ABSTRACT

A HOLOGRAPHIC SOLUTION

TO THE PROBLEM OF

THREE-DIMENSIONAL DISPLAY

IN THEMATIC CARTOGRAPHY

By

Robert W. McKay

Thematic cartographers, over the last fifty years, have attempted to incorporate the use of the third dimension in the product output of their field. Early attempts were inadequate by today's standards, owing to perceptual and portrayed dimensional inconsistancies. Subsequent development frequently failed to account for the needed realism expressed in terms of angular perspective. The culminating factor attributed to the failure in attaining the goal of three-dimensional representation was the inability of the existant two-dimensional media to portray a true three-dimensional message.

The development of holography has changed all of that. This technique offers the capability of presenting a three-dimensional image on an essentially two-dimensional medium of expression, a piece of film or

glass. Additional attractions, such as the ease of measurement and chronologically oriented multiplexing, can also be presented as definite advantages over conventional thematic cartographic techniques. The use of holography is the next step in the evolution of the cartographic field. The characteristics of holography demonstrated in this thesis prove that it is indeed a viable method for recording three-dimensional cartographic output on relatively conventional photographic film.

A HOLOGRAPHIC SOLUTION TO THE PROBLEM OF THREE-DIMENSIONAL DISPLAY IN THEMATIC CARTOGRAPHY

By

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Introduction

Off-axis holography is a technical process that can realize its result in a three-dimensional visual output of a three-dimensional diffuse object or scene. This process achieves this end by recording the interference pattern, resulting from the interaction of two coherent light wavefronts (emitted from a laser light source), on a photographic plate. One of these wavefronts is a complex wavefront produced by the reflectance of laser light off the physical components of a given diffuse object or scene. The other wavefront involved in this process is a plane wavefront that issues forth directly from the same light source. While off-axis holography was originally applied to two-dimensional graphic information, subsequent development of the technique has established the unique capability of three-dimensional display as its single greatest attribute.

As do holographers, so too, thematic cartographers seek the graphical display of information. Since the 1920's considerable attention has been paid to the portrayal of the third dimension by those of this field. Unfortunately, the three-dimensional limitations of the various media employed by thematic cartographers have negated any final realization of the three-dimensional objective.

It would seem, then, that the ability of holographic means to display the third dimension could be augmented by the desires of thematic cartographers so anxious to achieve those same ends. The result of this union could be the birth of a true three-dimensional thematic cartography.

Statement of Problem

The problem to be investigated might initially be stated as, "Is this union possible?" That is more of a technical question than the greater philosophical query of, "Should this union be made possible?" Both eventually must be answered; with the former, perhaps, most legitimately being based only upon affirmation of the latter.

To achieve this determination, the heritage of "three-dimensional" thematic cartography must be examined. False assumptions, inconsistencies, and shortcomings of various methods used in contemporary "three-dimensional" thematic cartography first must firmly be delineated. While the suggested creation may rightfully be true three-dimensional thematic cartography, it must still prove itself viable in a field that has been dominated since its genesis by two-dimensional graphics that utilized visual cues to gain the title (but not the body) of "three-dimensionality".

In this light, the importance of this thesis might be in terms of its search for truthfulness. The adoption of this technique could dispel the need for presenting illusions of three-dimensionality. If realism in any way subtends the "cartographic conscience" then that alone should serve as raison d'être for this conception.

Objectives

It is probably apparent that certain objectives of this thesis are couched within the previously broached questions. However, perhaps the ultimate goal of this work is to prove that three-dimensional thematic cartographic results can be achieved through the use of the essentially two-dimensional film plate used in the holographic process.

Hypotheses

I would first hypothesize that over the last fifty years thematic cartographers have been attempting to introduce and develop a concern for the portrayal of the third dimension. Secondly, these attempts, while coming closer to that goal with the passage of time, have not actually been able to portray the third dimension via two-dimensional media. In conclusion, it is hypothesized that the use of the holographic process allows for the production of a three-dimensional thematic cartographic output on an essentially two-dimensional medium of expression.

Definitions

X-Axis	-	the first rectangular coordinate
Y-Axis	-	the second rectangular coordinate
Z-Axis	-	the third rectangular coordinate
Two-Dimensional	-	defined by x and y axes
"Three-Dimensional"	-	defined by x and y axes, but giving an illusion of the z-axis
Three-Dimensional	-	defined by the x, y, and z axes
Physical Model	-	a three-dimensional structure, cartographic in nature, that is composed of statistical planes on the z-axis
Holography	-	a recording and viewing process that allows reconstruction of three-dimensional images of diffuse objects or scenes
Object Beam	-	a complex wavefront resulting from reflectance of a plane wavefront off a diffuse object or scene
Reference Beam	-	a plane wavefront emitted from the same source as the object beam

Hologram	-	the photographic record of the interference pattern resulting from object beam and reference beam interaction
Off-Axis Holography	-	producing holograms by separate object beam and reference beam, offset at an angle to one another

Data Sources

The nature of this thesis does not call for the collection of quantitative data, so prevalent in contemporary geographic research. Rather, the comparative and contrastive format of the investigation requires the use of qualitative data. The products of differing variable viewing angle techniques will be examined in regard to their respective abilities to meet the objective of achieving "three-dimensional" (and actual three-dimensional) portrayal of thematic information.

Owing to the static viewing angle of ninety degrees, "three-dimensional" hill shading techniques, such as Tanaka's inclined contour method, Brassel's oblique hill shading method, and other variations on the same theme will not be analyzed in the context of this thesis.

Several modes of representation will be applied to a common subject, total State populations of the midwestern United States. The techniques to be investigated are as follow:

1) two-dimensional base maps with volumetric symbols

2) block diagrams

3) physical models

In addition to these methods of representation, a new technique will be applied to the thematic mapping problem. This technique is that of:

4) off-axis holography

Data gathering will be accomplished by assembling and illustrating graphical products generated by the author. This output will consist of:

1) manually constructed drawings

2) SYMVU computer plot outputs

3) manually constructed physical model

4) off-axis transmittance holograms of model

5) multiplexed off-axis transmittance holograms of the model

6) photographs of holographically reconstructed image of model

7) photographs of multiplexed holographically reconstructed images of model in time sequence

8) photographs of holographically reconstructed images of model photographically multiplexed with a physical mensuration device in reconstructed image plane

Hypotheses Testing

The testing of the hypotheses will consist of applying the data to the qualitative analysis format illustrated in Figure 1. The questions asked in the analysis are reflective of greater awareness toward three-dimensionality as one progresses further through the process. Thus, the first hypothesis will be tested by noting at what point the various cartographic techniques respectively leave the questioning process. If the techniques are input according to the chronology of their development, and each successive input leaves the mainstream of the analysis at a greater level of penetration, the first hypothesis will be accepted.

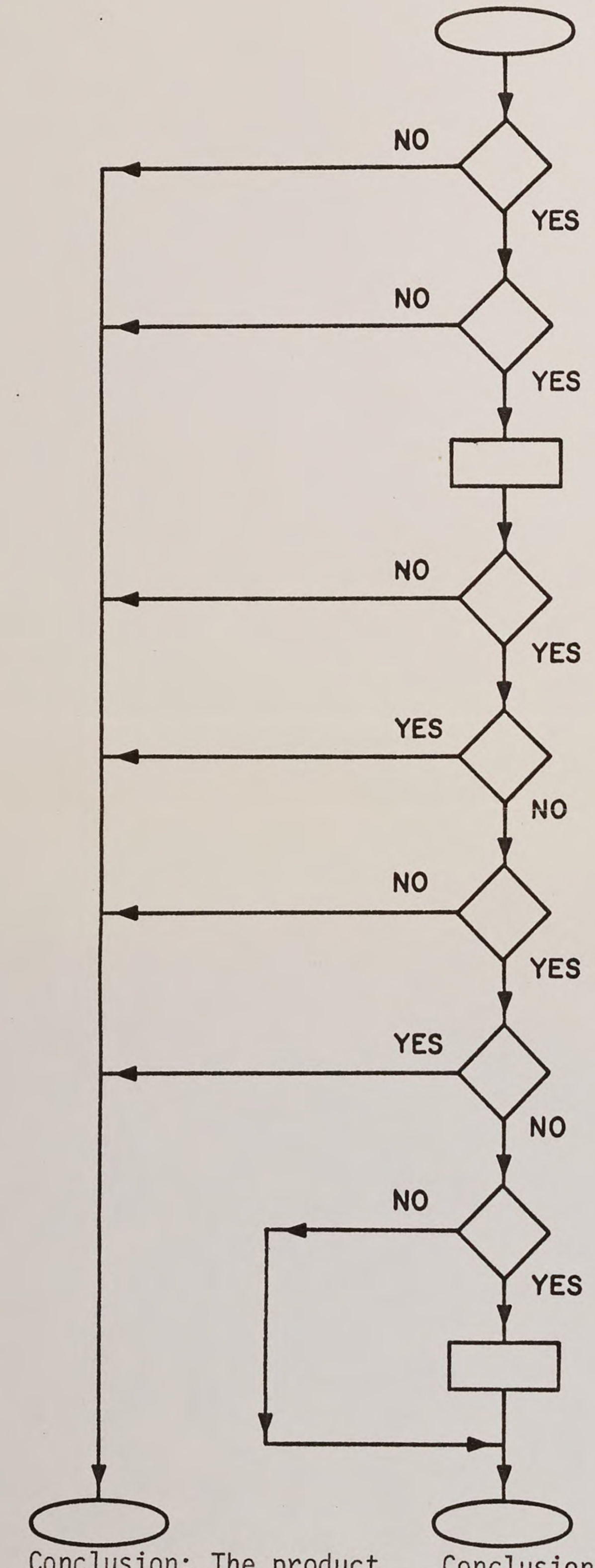
If all techniques, except the newly proposed method which utilizes off-axis holography, reach, "Conclusion: The product is <u>not</u> the optimal method for portraying three-dimensionality on a two-dimensional medium", the second hypothesis will be accepted.

If the newly proposed method that employs the off-axis holographic technique, reaches, "Conclusion: The product <u>is</u> the optimal method for portraying three-dimensionality on a two-dimensional medium", the third hypothesis will be accepted.

Graphic Presentations

Presentation of "three-dimensional" graphics will be accomplished by standard two-dimensional cartographic techniques utilizing pen and ink. Computer generated graphics will be used to display the output from the SYMVU computer

FIGURE I - ANALYSIS PROCESS



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mapping program. Photographs will be taken of all three-dimensional material relevant to the thesis. This includes photos of the model and the holographically reconstructed images.

Since photography is a two-dimensional form of visual recording, the three-dimensionality of three-dimensional images will be compromised somewhat, by necessity. Differential focusing, dependent upon photographic depth of field, will be submitted as "proof" for the three-dimensional nature of the holographically reconstructed images.

CHAPTER II

The Historical Basis of Dimensional Perception and Display

Early Man

The first physical observance of depth undoubtedly occurred in the early pre-history of mankind. It was not a conscious observation, but a natural one. It was natural in the same terms as the perception of heat or pain. It was simply a small part of the "total man".

Man utilized his natural attention to depth in his daily regimen. It was this attribute of depth perception that allowed him to survive. His success at obtaining food depended directly upon the keen edge of distance judgment. So, too, did the success of avoiding physical harm from beast or other men depend upon this perception.

As life continued, man found the desire to record his achievements. Recording took the form of graphical output upon cave walls. The meaningful highlights were rendered to future generations through pictorial accounts. These graphics attempted to portray life through the eyes of the beholder.

Commitment to realism had a place in these illustrations, too. It may have been a chance occurrence that first prompted early man to apply color to these figures, but it was certainly not mere happenstance that promoted the consistent application of brown to the figures of creatures that were, in reality, brown in color.

An additional aspect that relates to realism is that of the distance-size relationship. The cave dwellers might have first recognized this when noticing the apparent size of a creature from a distance. The closer the creature ventured, the greater its apparent size became. This realization, too, was incorporated in their drawings. In illustrating an assemblage of beasts, those that were a greater distance from the imaginary point of observation were drawn as smaller beasts.

The Renaissance

The Renaissance ushered forth an increased awareness of realism. Throughout the art-work of this time, fine attention was paid to distance-size and angular relationships. Man was trying to illustrate via the essentially two-dimensional medium of brush and canvas the actual perceptions he obtained from his three-dimensional optical abilities. However, no amount of toil and tribulation could actually achieve these ends. The fact remained that at that time there existed no method for utilizing two-dimensional means to achieve three-dimensional results. The use of distance-size and angular relationships worked toward giving all the visual cues that were associated with depth, but in no way could the elusive quality of realism be delivered.

The Renaissance not only emphasized the importance of realism, but provided the technique and media necessary for the portrayal of depth. This was achieved by the many artists who made use of sculpting techniques. Frequently, these men were the same that used brush and canvas. It is rather difficult to determine which area of their talents most influenced the other, but one might theorize that the acute perception of depth so necessary for sculpting dramatically influenced the perceptions rendered to canvas. In the case of sculpting, these people were presented with a medium that was entirely suitable for the presentation of three-dimensionality.

The actual material used for the portrayal of sculpting is of little concern in the context of three-dimensionality. Whether the finished product was stone or bronze, it was three-dimensional just the same. The unfortunate aspect of this artistic form was that the achievement of the three-dimensional quality had to be paid for by the price of existence in physical space. As opposed to a painting of the Last Supper, a sculpture would have achieved depth at the cost of obfiscating the usefulness of that portion of the room in which the sculpture was situated.

Early Cartographers

There is no doubt that the actual origins of cartography go back to the first person who traced his path, the location of animals, or the course of a river in the sand with a stick. However, cartographers of the western world generally seem to trace the pragmatic foundation of their discipline to the fifteenth century. It was during this period that man sought the need to record his location relative to the larger geographical area of his concern.

By the Age of Discovery, this area of concern had extended to well beyond the horizon. It was no longer feasible to portray all essential information to an associate by means of a few crude line-drawings in the sand. Furthermore, there arose the need to take this information away from the point of original composition to other locals.

The realm of the world was expanding rapidly. The services of cartographers were employed to meet this challenge, primarily through the production of portolani and other forms of nautical charts. The world trade routes were developing upon the oceans. The guidance of vessels over these unknown surfaces to their ports-of-call became a paramount concern to many, including the cartographers.

It is significant to note that the fundamental under-pinnings of this field had not changed one iota from the time when cave dwellers drew lines in the sand. The integral importance of man, land, and water had been carried-on throughout the evolution of mankind. However, so too, another fundamental aspect did carry through from time immemorial . . . . the recording of the man-land-water significance upon a two-dimensional medium.

It is easy to see why nautical charts developed to indicate only the x and y axes. Since the water bodies travelled were perceived as planar surfaces, there was no need to portray a z-axis. All necessary information could be shown to relate only to that plane. Even the three-dimensional qualities of shoals and reefs had little importance to the seafarers other than the fact of their location upon that two-dimensional perceptual plane.

The point being made is that the eventual development of the two-dimensional Cartesian Coordinate System in the seventeenth century by DesCartes was a very systematic and predictive occurrence. Given the fact that the direction of travel and relative location were viewed in planar terms, it is quite logical to assume that any representation of the same would be viewed in similar terms. The importance of the Cartesian Coordinate System is most pointed in its direct and meaningful applicability to the representation of the situation from which it had been derived.

Eventually, this planar view of the earth changed. Perhaps it was due to exploration inland from the seacoasts. In any case, as man traversed the land surface, cartographers were required to include new types of information to the products of their trade. If mountains were found at a certain location, it became the responsibility of the cartographers to portray this aspect. A form of crude symbolization was first adopted to achieve this representation, but in no way did it even come close to anything that could be deemed realistic.

Inappropriately, instead of developing a method from the newly existent situation, cartographers manipulated the situation to fit their existing method. Nautical charts assumed a constant plane and the subsequent necessity of portraying only the x and y axes upon that plane. The addition of landforms or other three-dimensional items, while obligating consideration, did not receive consideration for the portrayal of that heretofore unrecorded dimension, the z-axis.

CHAPTER III

Three-Dimensional Composition

Axes

The Cartesian Coordinate System was originally developed from the mathematical modeling of René DesCartes in the seventeenth century. While some contemporary cartographers might scoff at the need for definition of this system, it is necessary in the context of this thesis.

"Cartesian Coordinate System -- 1) A two-dimensional coordinate system in which the coordinates of a point are its distances from two intersecting, often perpendicular straight lines, the distance from each being measured along a straight line parallel to the other. 2) A three-dimensional coordinate system in which the coordinates of a point are its distances from each of three intersecting, often mutually perpendicular, planes along lines parallel to the intersection of the other two."[1]

It is clear that both denotative meanings are derived from a common philosophical vantage. However, in practice, the connotative meanings accepted by many cartographers are derived from the realm of their experiences. This is to say that those cartographers whose experience has been predominantly confined to two-dimensional work will find it difficult to think in terms of a three-dimensional context. For that reason, these relationships will be examined.

Owing to the first definition, two axes must be defined. Those are the abcissa and the ordinate. The abcissa is the x-axis, the first rectangular coordinate[2]; that measured on the horizontal axis. The ordinate is the y-axis, the second rectangular coordinate[3]; that measured on the vertical axis. The relationship of these axes is shown graphically in Figure 2. The representation is functionally planar and therefore ideally suited for the two-dimensional character of a pen and ink drawing.

The three-dimensional definition introduces a third coordinate. This is the zenith -- the z-axis, the third rectangular coordinate[4]. The standard graphic mathematical portrayal of the x, y, and z axes' interrelationship is shown in Figure 3A. The 'O' indicates the origin in this right-handed coordinate system. The dashed line indicates that the axis is extending out of the page toward the viewer.

This imaginary three-dimensional figure could be "laid on its back" without destroying the relationship of the

FIGURE 2 - TWO-DIMENSIONAL AXES

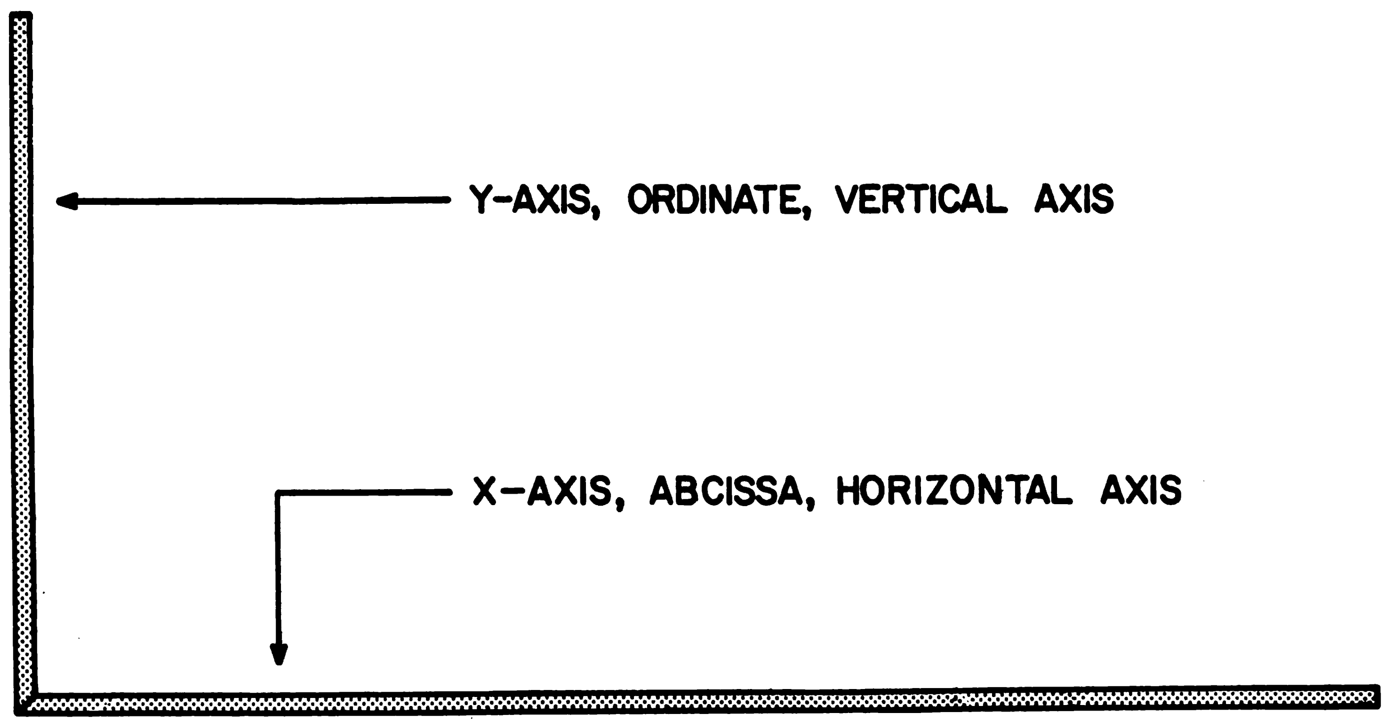
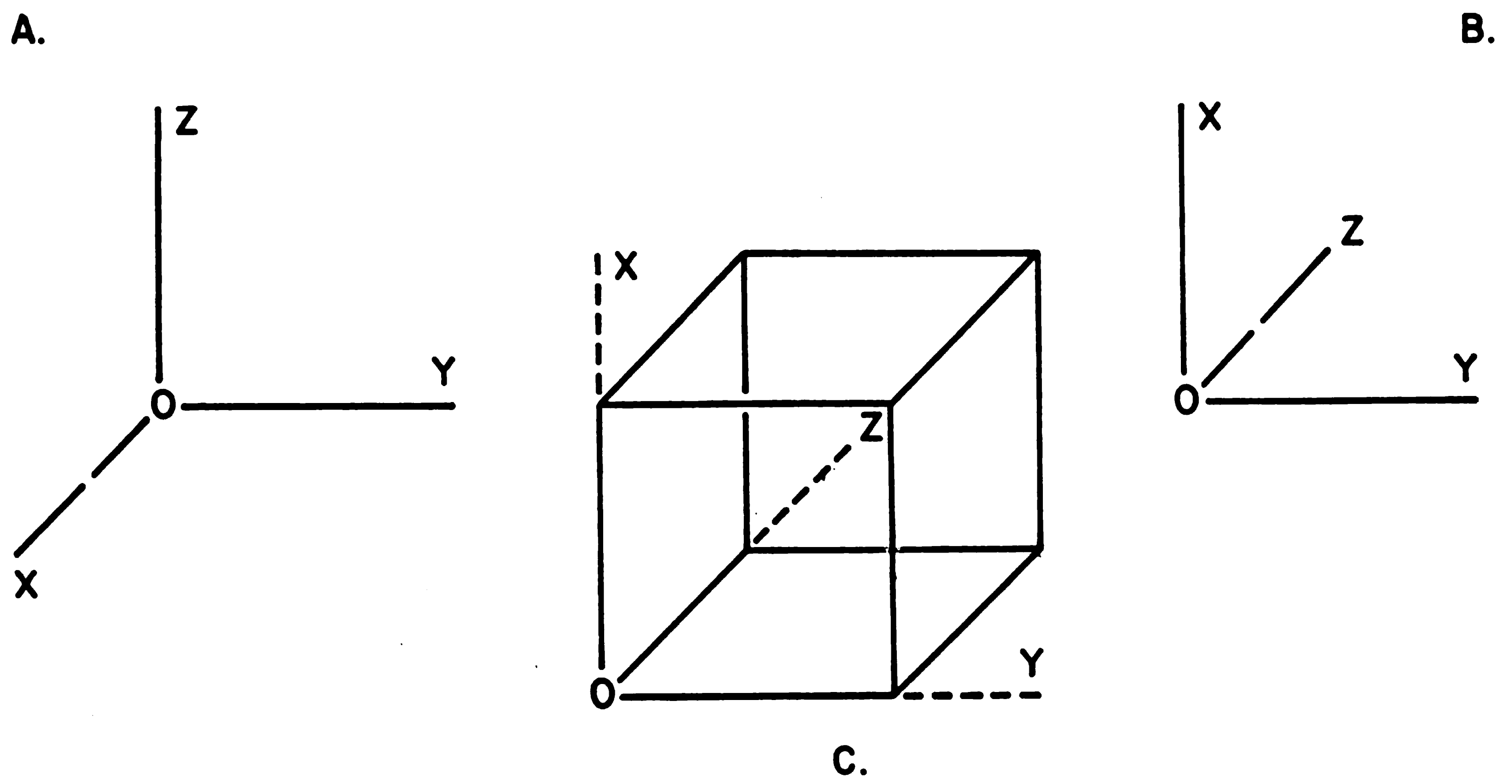


FIGURE 3 - MORE COMMON X-Y-Z RELATIONSHIP



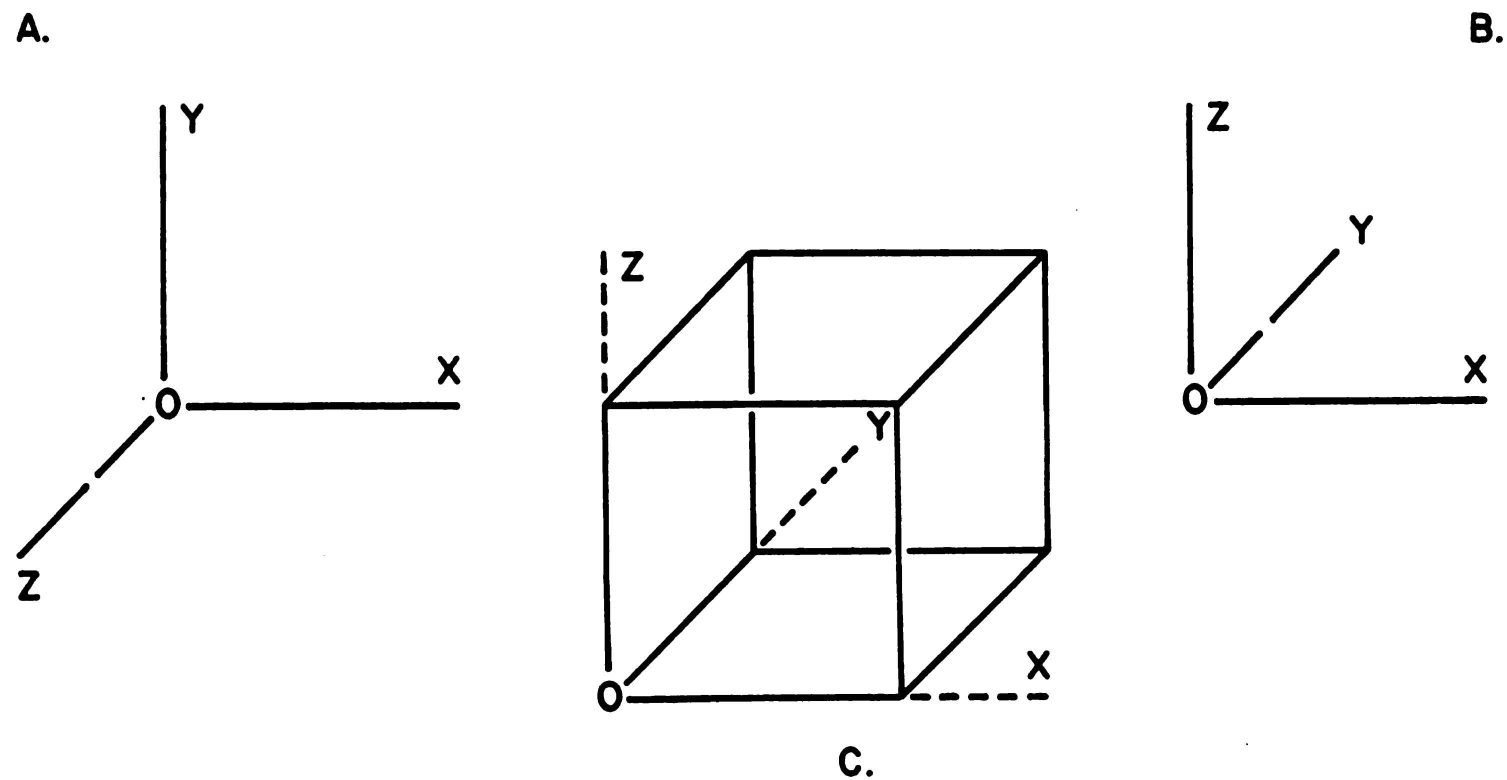
axial planes. If this were done, the illustrated version would appear as in Figure 3B. The z-axis should be imagined extending back through the page. Applying this relationship to a cubical structure would result in the portrayal shown in Figure 3C. Broken lines are utilized on the far side of the cube in an attempt to minimize the possibility of optical illusion.

While Figure 3 illustrates the more common x-y-z relationship, another visual portrayal is also acceptable.[5] This is shown in Figure 4A. Figures 4B and 4C have received the same relative adjustments in their visual representations as did Figures 3B and 3C. The purpose of pointing out these differing modes of x-y-z relationship is not to confuse the reader. It is merely to set the stage for continued discussion. We will find that thematic cartographers have utilized both of these representations in their art. Consequently, a working base of common understanding must be established at this time.

Perspective

Simply stated, perspective is the way in which we see an object dependent upon the viewing point, the elevation of that point above the horizon, and the azimuth on the horizon.[6] Perspective is utilized significantly for cartographic purposes in the attempt to provide a mapping

FIGURE 4 - ALTERNATIVE X-Y-Z RELATIONSHIP



technique that is responsive to the three-dimensional nature of spatial data. This attempt is commonly referred to as "three-dimensional" mapping.[7]

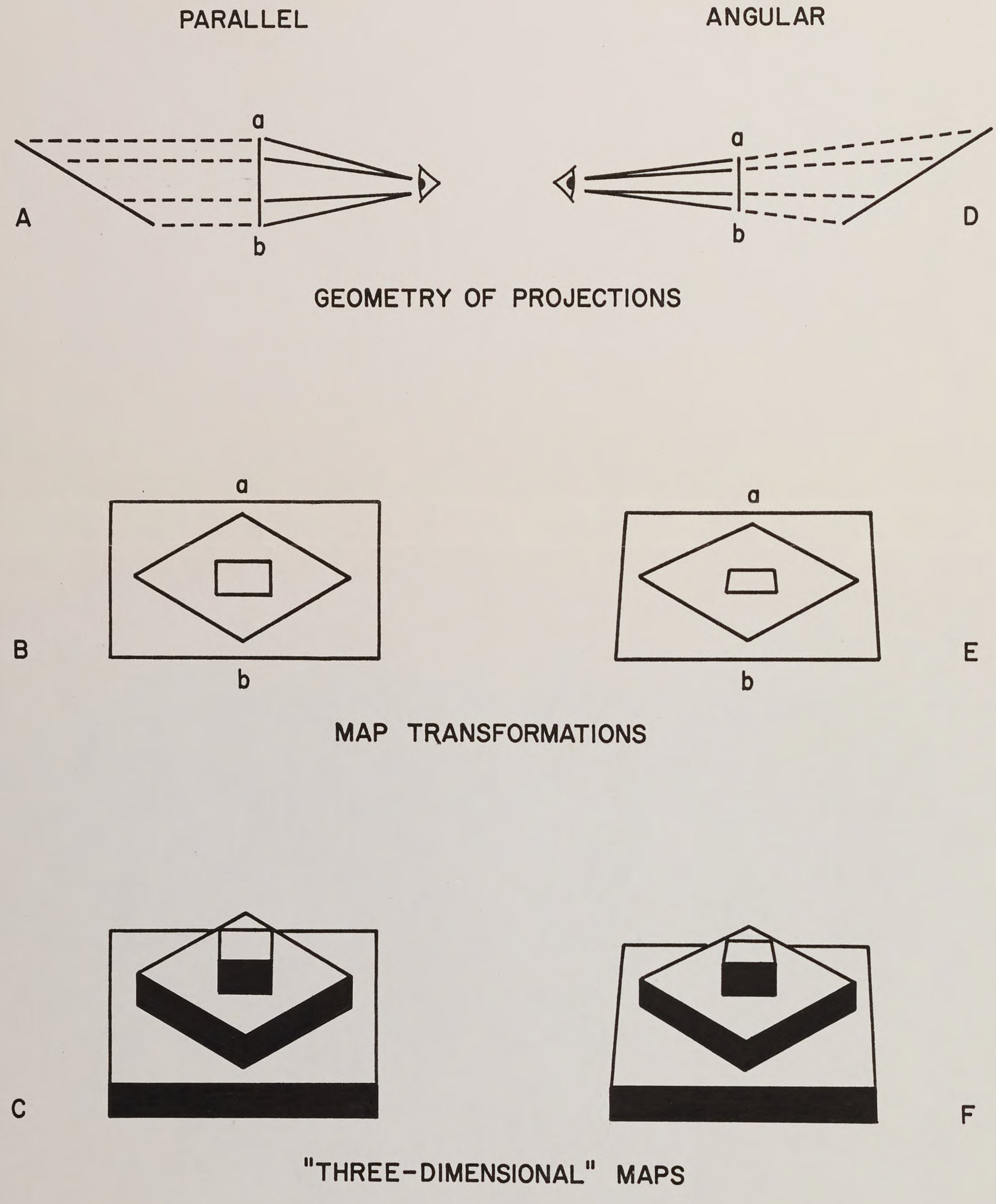
The medium of "paper and ink" can never actually achieve true three-dimensional results. This is due to the inherent lack of the third dimension in which to work. Therefore, this "three-dimensional" mapping attempts to provide certain visual cues to the reader that will create the illusion of depth.[8] The most singularly convincing item that can be attributed to the success of this illusion is that of perspective.

Perspective is a very general term. In "three-dimensional" mapping, differing types of perspective may be employed. We shall examine these types and various sub-types in terms of their construction methods and resulting products.

Parallel Perspective

Parallel perspective utilized parallel projectors extending from a planimetric map.[9] See Figure 5A. This map is assumed to be lying thirty degrees off the horizontal plane. The parallel projectors extend to the plane of perspective view, which is normal to the angle of view. The image appearing on the plane of perspective view is referred to as a parallel perspective transformation, such

FIGURE 5 - PROJECTIONS



as that shown in Figure 5B. The surface is then elevated along the vertical axis in a manner described by Stacey to provide a parallel perspective "three-dimensional" map as shown in Figure 5C.[10]

Angular Perspective

Angular perspective differs in theory from parallel perspective in that the projectors converge, rather than extend in a parallel manner, at the plane of perspective view. A cross-sectional illustration is shown in Figure 5D. The transformation at the plane of perspective results in the transformation appearing as in Figure 5E. An angular perspective "three-dimensional" map constructed from this transformation would appear as in Figure 5F.

A significant difference exists between the graphics that result from angular perspective and those that owe their form to parallel perspective. In the transformations of parallel perspective, the x and y axes are perpendicular to one another. This is not the case with that transformation resulting from angular perspective. The "sides" of the transformation are sloping inward. If these "sides" were extended, they would eventually intersect. Consequently, it may be noticed in Figure 5E that the horizontal line above "b" is longer than the horizontal line located under "a". Visual contrast and comparison can be facilitated by examining the transformations and the "three-dimensional" maps, resulting from the parallel and angular perspectives, side by side in Figures 5C and 5F.

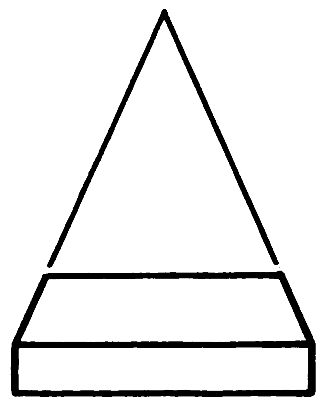
Furthermore, while it may be difficult to perceive, convergence takes place on the vertical plane as well as on the horizontal plane when angular perspective is used.[11] Since this fact is not accounted for in parallel perspective, that type of perspective can only result in a vertical exaggeration being expressed in the cartographic results. In viewing Figures 5C and 5F again, it can be seen that the "three-dimensional" map resulting from parallel perspective extends further along the vertical axis than does the product generated by the employment of angular perspective.

A sub-type determination can additionally be made in the case of angular perspective. This generally applies to the azimuth on the horizon above which the viewing point is located. These sub-type classifications are referred to as one-point and two-point perspective.

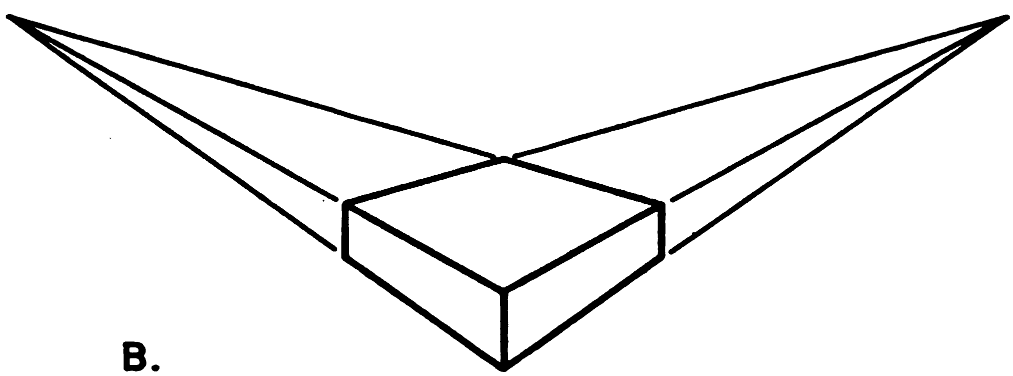
One-point perspective assumes the leading edge of the block base to be parallel with the horizon. As one progresses vertically, it will be noticed that the "sides" of the block will slope in a manner to intersect at a single point upon the horizon. A drawing is shown in Figure 6A to illustrate an example of one-point perspective.

FIGURE 6 - PERSPECTIVE VIEWS

A.



ONE-POINT PERSPECTIVE



B.

TWO-POINT PERSPECTIVE

Two-point perspective is assumed when a model is presented with a corner toward the viewer. The "sides" on the x-axis and those on the y-axis each focus, respectively, upon separate points located on the horizon. An example of a block viewed in two-point perspective is seen in Figure 6B.

Through the preceeding discussion, a theme has been developing. The basis of this theme is that types of perspective have differing degrees of "legitimacy". This is to say that in relation to the manner in which we would perceive an actual physical model with our eyes, angular perspective is the most successful method of alluding to that perception in contemporary "three-dimensional" cartography.

However, perspective, as we have seen illustrated thus far, has not always been used by those aspiring to introduce the third dimension into cartographic output. An evolution took place that must be understood to evaluate the state of the art today. Hopefully, we can subject examples from this evolution to a form of qualitative analysis that will allow us to perceive the limiting characteristics of these differing methods utilized in the portrayal of "three-dimensionality".

CHAPTER IV

"Three-Dimensional" Thematic Cartography

Derivation from Topographic Mapping

"Since the eighteenth century the map has been used as a tool to show the spatial distribution of physical, social, and economic phenomena. Such maps, which present a particular theme, are often distinguished from the topographic map by the term thematic maps."[12] Some might say that thematic cartography begins where topographic cartography "leaves off". This is to say that thematic mapping generally takes place on a topographic base map. From the preceeding statement of Hodgkiss', it is apparent that the reliance of thematic cartography upon topographic cartography is chronological as well as physical.

Likewise, "three-dimensional" cartography owes its genesis to topographical mapping, as this sort of mapping was first fostered in the United States by the U.S. Geological Survey.

Early in the twentieth century, the two aspects of three-dimensionality and thematic cartography were merged. The results combined a thematic attitude with a "three-dimensional" mode of portrayal. Many of the early attempts in this field set firm precedents upon which subsequent development arose. An examination of this development will strive to show us the "three-dimensional" thematic cartography of today by understanding the work of yesterday.

Dimensional Inconsistency

Sten De Geer published an article in 1922 entitled "A Map of the Distribution of Population in Sweden: Method of Preparation and General Results".[13] This method was developed in a response to the need for displaying quantitative data. De Geer felt that the "averaging" effect of the choropleth technique was detrimental to the development of a genetic-quantitative geography.[14]

As a solution to the prevailing inadequacies of the contemporary methodology, De Geer proposed the use of "three-dimensional" representation based upon the existing theory of the dot method. It was his belief that the graphical representation of spheres could be drawn in a manner coexistent with dots. The fundamental dichotomy of two-dimensional representation versing that of three dimensions had just found the basis of its origin.

Symbolism

It is strange, though, that this was not noticed by the cartographic community. Instead, in 1928 Guy-Harold

Smith published "A Population Map of Ohio for 1920" utilizing the same basic technique.[15] The only distinction between the two methods was Smith's alteration of the symmetrical arrangement of dots utilized by De Geer to an asymmetrical arrangement of dots.

In that well-known product of Smith's (excerpt shown in Appendix A), we notice that the "spheres" are actually circles. Appropriate shading is rendered in an attempt to create the illusion of spherical structure, but apparently Smith conceptually viewed these figures as circles. This argument can be supported by noting the locations of these symbols. If these figures actually were perceived by Smith as spheres, their relative locations would be positioned by consideration of the point of spherical tangency on each sphere-plane interface. Thus, the "resting point" of each sphere would be commencerate with the planar location of the respective cities of which the spheres represent the population. Instead, it can be noticed that if the "spheres" are perceived as circles, the respective centers are accurately positioned over the appropriate city locations.

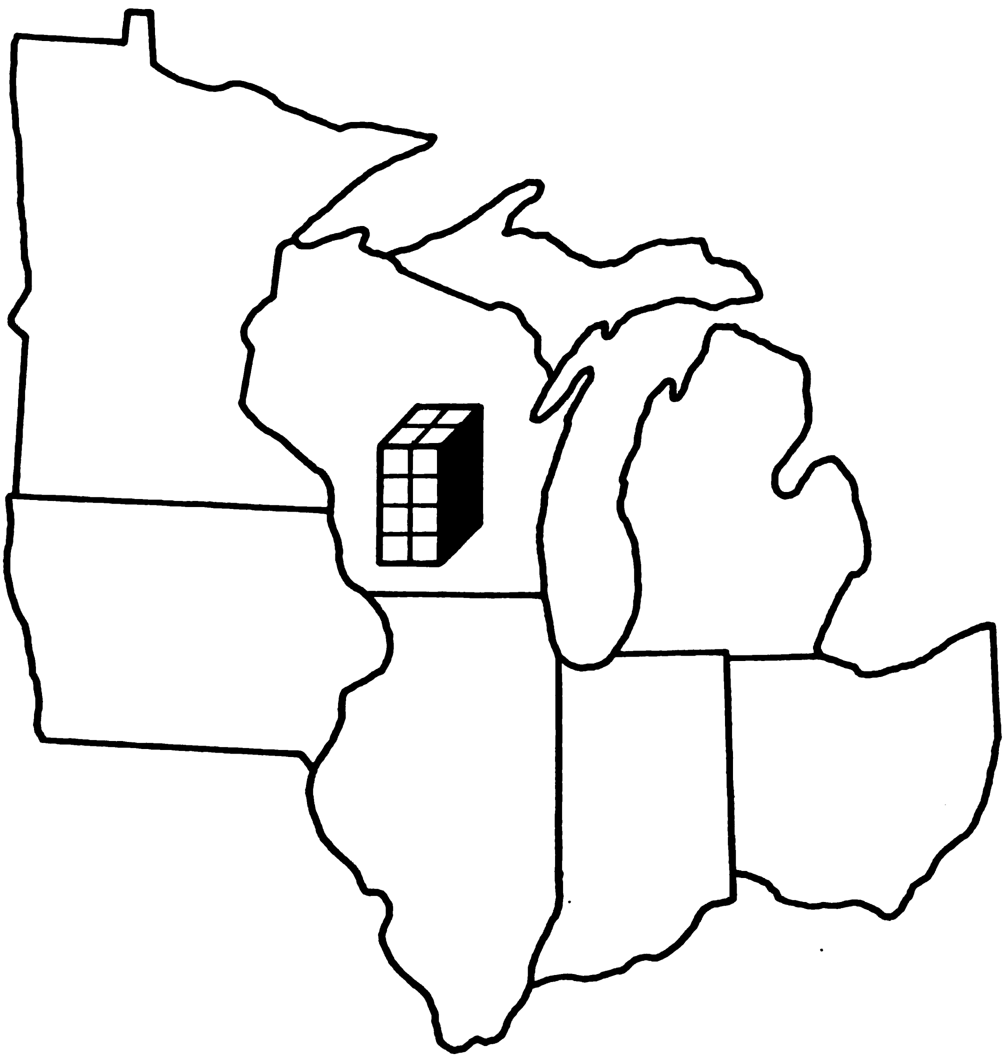
Dimensional inconsistency is a problem of this method. While this topic will be discussed subsequently in reference to symbology in total versing the base map, it is apparent that in this case dimensional consistency has not been considered even in the portrayal of all symbology. "Three-dimensional" figures have been interspersed with two-dimensional dots. The result is one of dimensional confusion on the part of the reader, derived from dimensional inconsistency of symbology presented by Smith.

As was mentioned earlier, dimensional consistency can also be viewed in terms of two map components. The first is the physical base on which the quantitative data rests, and the second is the symbology itself. While Smith failed on the latter count, Erwin Raisz overcame this problem through the use of cube-like symbols referred to as "block piles", only to fail on the larger scale of consideration that places these two elements in concert.[16]

Raisz presented an article entitled "Block-Pile System of Statistical Maps" in 1939.[17] It was his desire to provide a technique that could overcome the lack of commensurability and the subdivision difficulty inherent with the use of "spheres". A publication entitled "Geographical Distribution of the Mineral Industry of the United States" appeared two years later.[18] An example of that technique is shown in Figure 7.

Throughout Raisz's work we find that the States were drawn in respect only to two dimensions, while the "block-

FIGURE 7 - RAISZ'S BLOCK-PILE



piles" were constructed to portray the illusion of three-dimensionality.

Referring to Figure 8, we can see that a cross-sectional view shows tha planes to which the base map and the "block-piles" are oriented, respectively. The "block-piles" have been constructed in such a manner that the imaginary base upon which they rest is forty-five degrees off the plane on which the base map has been constructed. This disparagement, while perhaps not immediately noticeable to all map readers, should be recognized as dimensional inconsistency to anyone at all familiar with the observance of depth in the real world.

Wilbur Zelinsky utilized isometric symbology in an article entitled "An Approach to the Religious Geography of the United States: Patterns of Church Membership in 1952".[19] The use of these particular volumetric symbols did offer the possibility of overcoming the weakness presented in the works of Raisz. Unfortunately, Zelinsky was apparently unaware of this and thusly proceeded to induce the same problem in his cartographic output.

Figure 9 shows several midwestern States with an isometric cube constructed and displayed in the same manner as those used by Zelinsky. Again, we see by cross-sectional illustration in Figure 10 that inconsistency

FIGURE 8 - PROJECTION PLANES USED BY RAISZ

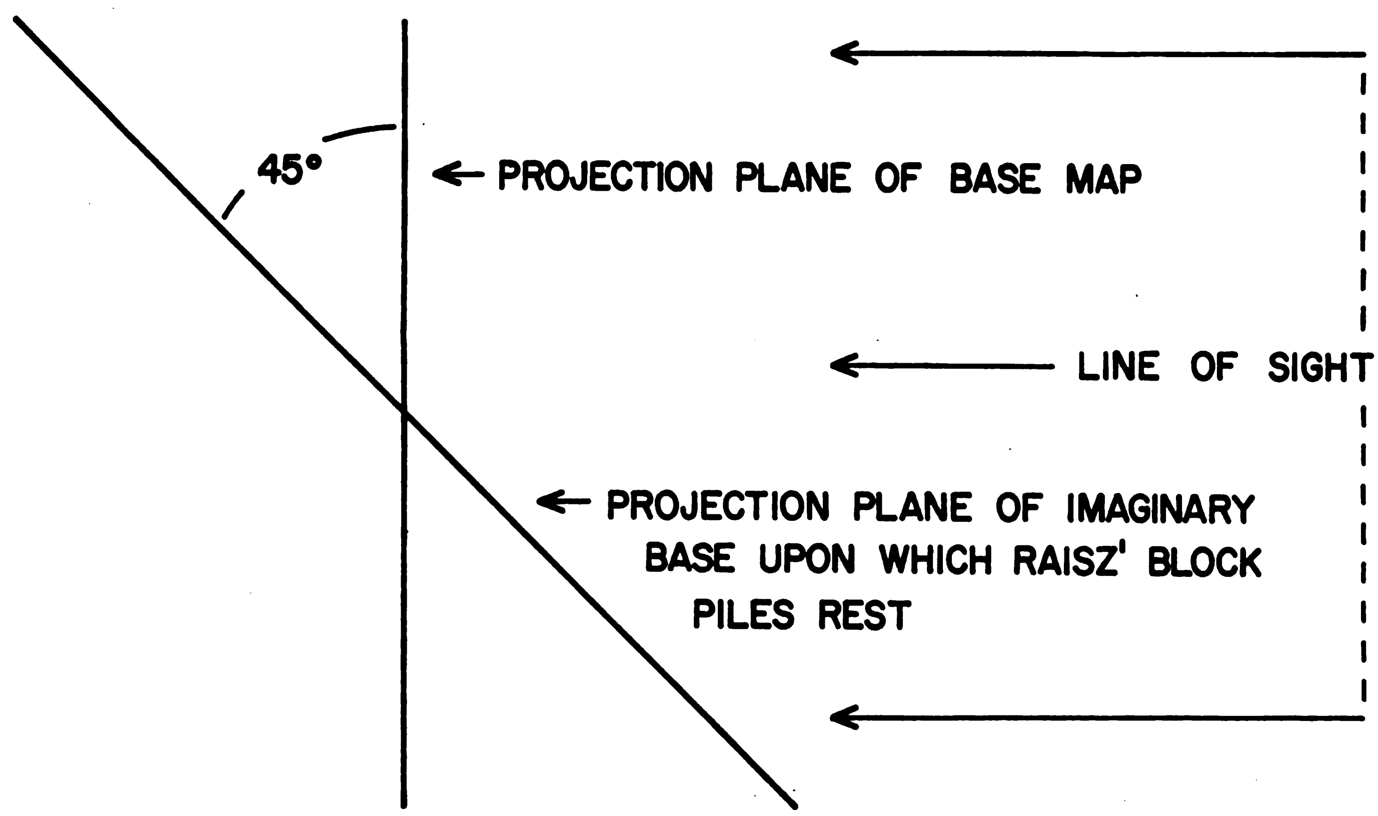


FIGURE 9 - ZELINSKY'S ISOMETRIC CUBE

exists. However, consistency could have been realized by Zelinsky had he adjusted either the projection plane of the base map or the projection plane of the imaginary base upon which the isometric cubes rest. By adjusting the former to fit the latter, the product as shown in Figure 11 can be derived.

The cross-sectional diagram of this derivation, Figure 12, illustrates that the two planes in question are superimposed on one another. Furthermore, dimensional consistency can be achieved by utilizing the isometric symbolism combined with an isometric projection of the base map. While Figure 11 is consistent in terms of the projection planes, true dimensional consistency can be gained by incorporating a form of total isometric perspective that would view the scene from the southeast and appear as in Figure 13.

Perspective View

While the cartographic examples, both reproduced and newly generated, have shown an increase toward a greater appearance of "three-dimensionality", it may be noticed that they are all deficient in terms of angular perspective. This is not too difficult to believe when we realize that angular perspective has been essentially disregarded by thematic cartographers throughout the field, from past to present. This point is substantiated by the conspicuous

FIGURE 10 - PROJECTION PLANES USED BY ZELINSKY

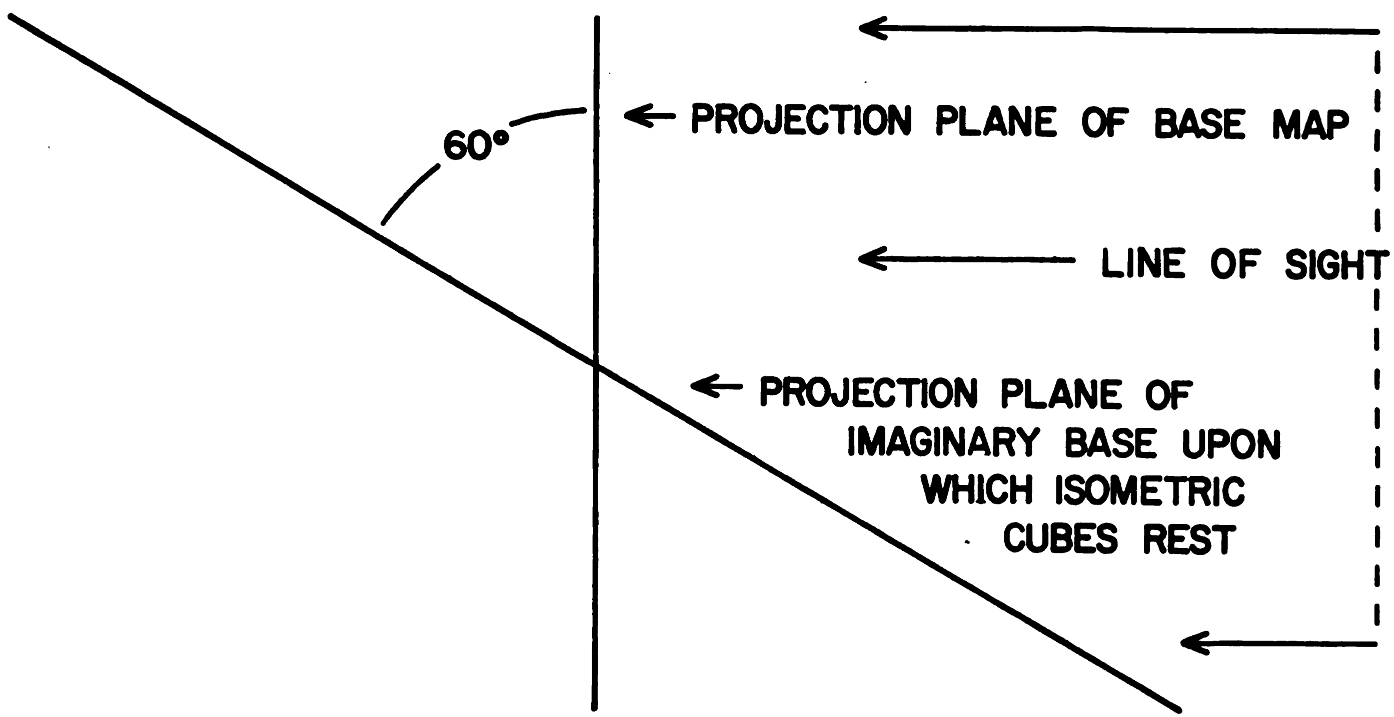
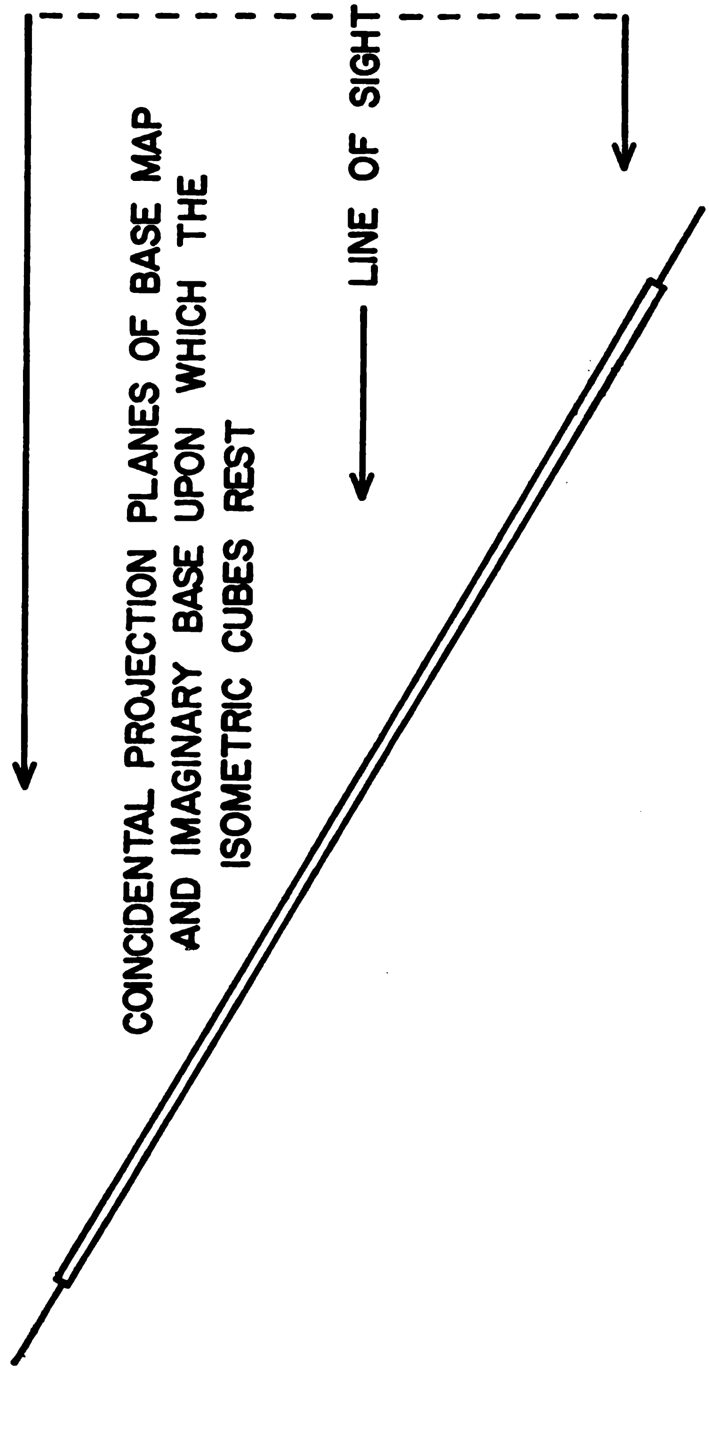


FIGURE 11 - CONSISTENT PROJECTION PLANES



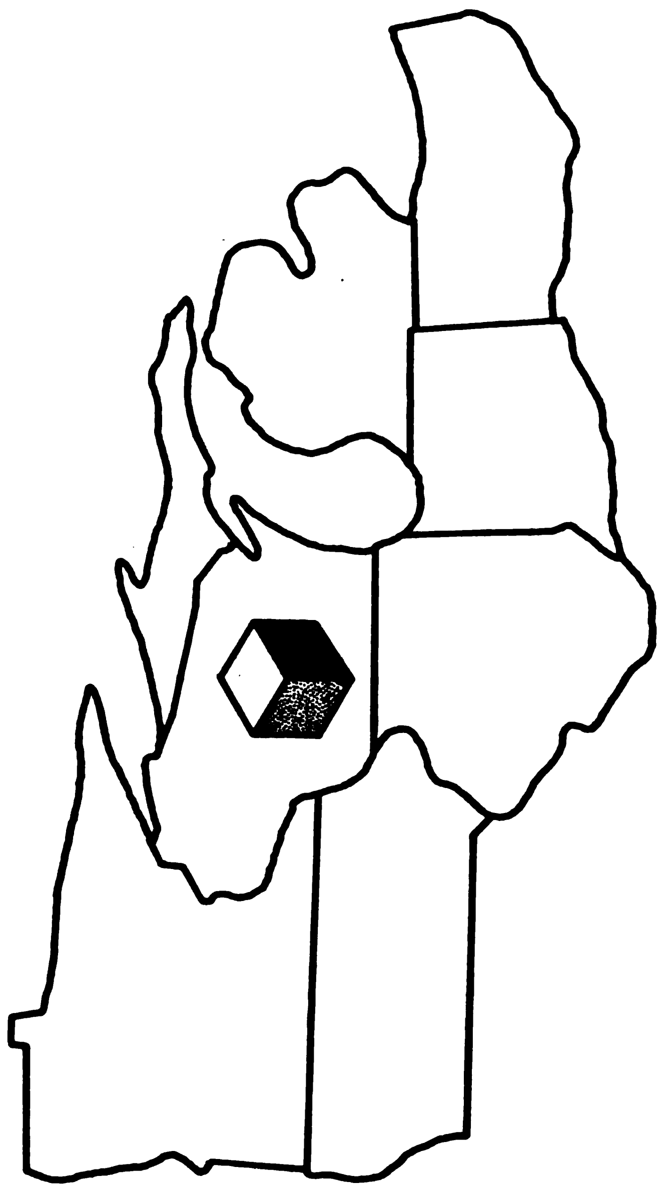
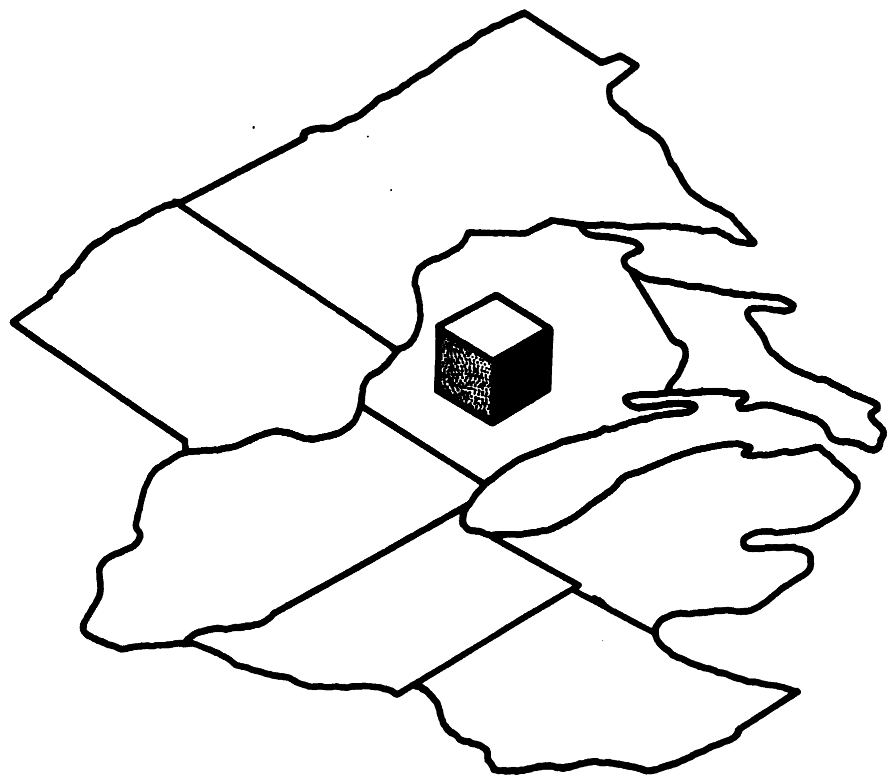


FIGURE 12 - SUPERIMPOSED PROJECTION PLANES

FIGURE 13 - TOTAL ISOMETRIC PERSPECTIVE



absence of documentation concerning either theoretical or methodological considerations of angular perspective in "three-dimensional" thematic cartography. Furthermore, actual cartographic products of a thematic nature employing the use of angular perspective are yet to be found in the literature.

Neglect in Landform Mapping

Occasionally, reference to angular perspective in the broader classification of cartography *per se* can be found. However, these references are usually concerning topographic cartography. Axel Schou applied this consideration to landforms in 1941.[20] Additionally, commentary on one-point and two-point perspective in the graphical rendering of landforms is highly stressed by Lobeck.[21] Generally, though, its use even in block-diagrams (of landforms) or perspective maps of the terrain is discouraged. Jenks and Brown describe the use of angular-perspective maps as not being economically feasible,[22] while Monkhouse and Wilkinson say, "block-diagrams (of landforms) can be constructed in either one-point or two-point perspective, with considerably more labour."[23] It is significant, then, that the application of angular perspective has yet to be introduced to "three-dimensional" thematic cartography.

It is quite understandable that the use of angular perspective has not yet penetrated the entire field of "three-dimensional" thematic cartography. The basis of "three-dimensional" cartography, in general, has been topographic, not thematic. In light of this, the physiographic method attributed to those such as Lobeck and Raisz[24] was fundamentally concerned with the correct planimetry of maps.[25]

Thematic cartographers have traditionally been followers of methods used for topographic mapping. Quite frequently, thematic and topographic cartographers have been one in the same. Owing to this, those in the field of thematic cartography have not been original, but instead have applied methods developed for the portrayal of topography to the problems of portraying thematic information. Methodology applied to topographic mapping was never seriously challenged as to its thematic suitability. One such method is the physiographic method. Another is the terrain diagram proposed by Dufour.[26] The result has been the adoption of methods for portraying planimetrically correct three-dimensional topographic information to the thematic arena in which three-dimensionality might be of importance, but in which planimetry is of lesser consequence.

Neglect in Thematic Computer Mapping

The upsurging utilization of computer plotting capabilities in recent years has furthered the disregard for angular perspective. Numerous programs have been developed to portray statistical data in "three-dimensional" form. Some of these programs have been adopted by thematic cartographers. One such example is the SYMVU program that was developed at the Harvard Laboratory for Computer Graphics and Spatial Analysis as it operates on Michigan State University's CDC 6500 computer.[27]

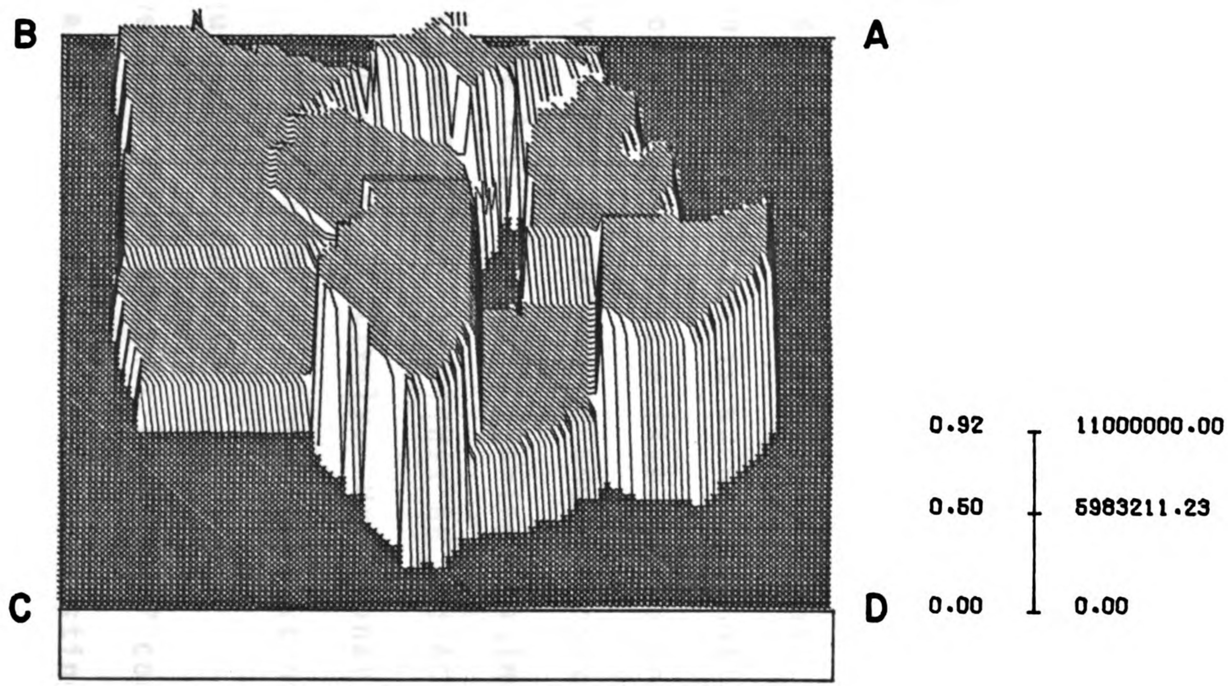
The SYMVU program allows for the construction of a "three-dimensional" drawing. It may be applied in a manner to graphically portray a statistical surface defined by points or one composed of conformant areas. We shall be concerned with its relevance in the latter case. When this program is applied to a subject such as population in the States of the Union, the States are drawn to appear as geometric solids. The height, or z-axis, is scaled so as to be proportioned to the predetermined variable. This figure is constructed upon a "block" to further enhance the three-dimensional effect.

Computer graphics of this nature are appreciated by many people for a variety of reasons. Consistent line work is one. Far more important, though, is the capability of this program to portray the data easily from differing points of view. The altitude, or viewing angle, can be adjusted from zero to 359 degrees. Scaling and shading patterns are variable within limitations, as well. Most significant, however, is that all of these alterations can be performed merely by changing a few numbers on two control cards.

Incidentally, while the SYMVU program does retain the capability to produce output in two-point angular perspective, this option requires deliberate action on the part of the user. Assuming that most people using a "canned" program will take advantage of as many default options as possible, the isometric projection would be unconsciously selected most of the time. This owes to the fact that the isometric projection is the default option for projection type in the SYMVU program.

Figure 14 shows the SYMVU program as applied to population of the midwestern United States in 1970. Mensuration of the population is accomplished by either visual comparison or by physical means utilizing the scale constructed on the apparent z-axis. It might be worthy to mote that determination of population cannot be made directly from the "three-dimensional" representation, itself. Without the scale appearing in concert, the map is quantitatively meaningless.

FIGURE 14 - PARALLEL PERSPECTIVE



MIDWESTERN U.S. POPULATION --- 1970

AZIMUTH = 0 ALTITUDE = 45
*WIDTH = 4.00 *HEIGHT = 1.30

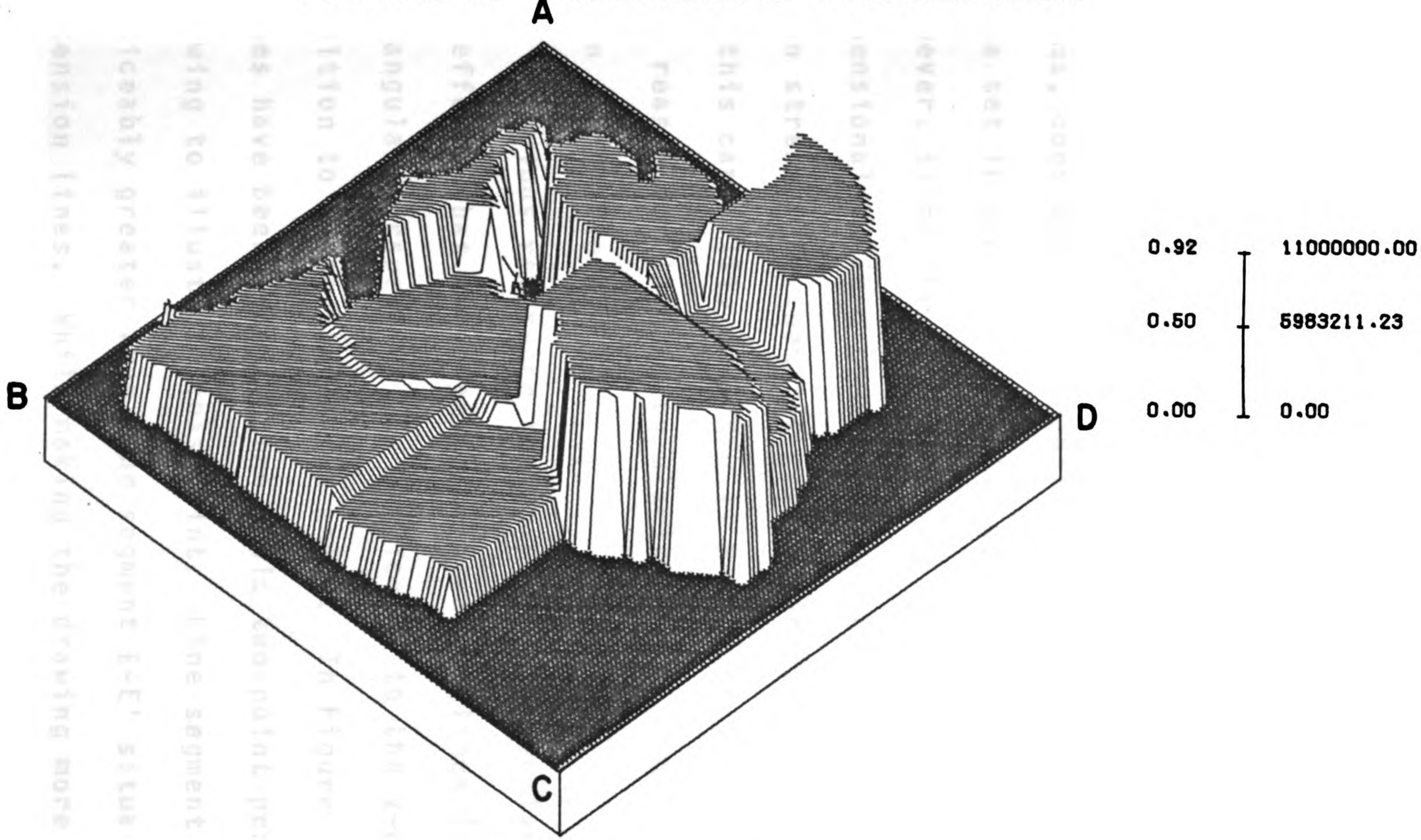
* BEFORE FORESHORTENING 05/12/75

Figure 14 presents an additional problem, as well. In it the significance of angular perspective has been ignored, totally. In this case the angular perspective would be one-point perspective. The sides of the "blodk" (y-axis) should appear to be sloping inward to a focal point on the horizon. While the exact slope could be determined from knowing the base dimensions, viewing angle, and distance of viewing, it is still valid to state that line AB should be shorter than line CD.

Figure 15 views the isometrically projected "three-dimensional" structure from a corner. In this case the lack of two-point perspective is much less noticeable than was the lack of one-point perspective in the preceeding figure. However, the violation of angular perspective has occurred none the less. If this drawing was in two-point perspective, we would find that lines AB and AC were shorter than lines CD and CB, respectively. Unfortunately, this is not the case, and the drawing is concluded as not being in two-point angular perspective.

Again, we have found another example of contemporary cartographic acceptibility that fails to distinguish itself in terms of realism. This aspect's importance has been stated by Jenks and Crawford along with those of clarity and aesthetic qualities.[28] However, without any consid-

FIGURE 15 - ISOMETRIC PROJECTION



MIDWESTERN U.S. POPULATION --- 1970

AZIMUTH = 45 ALTITUDE = 45
*WIDTH = 4.00 *HEIGHT = 1.30

* BEFORE FORESHORTENING 05/12/75

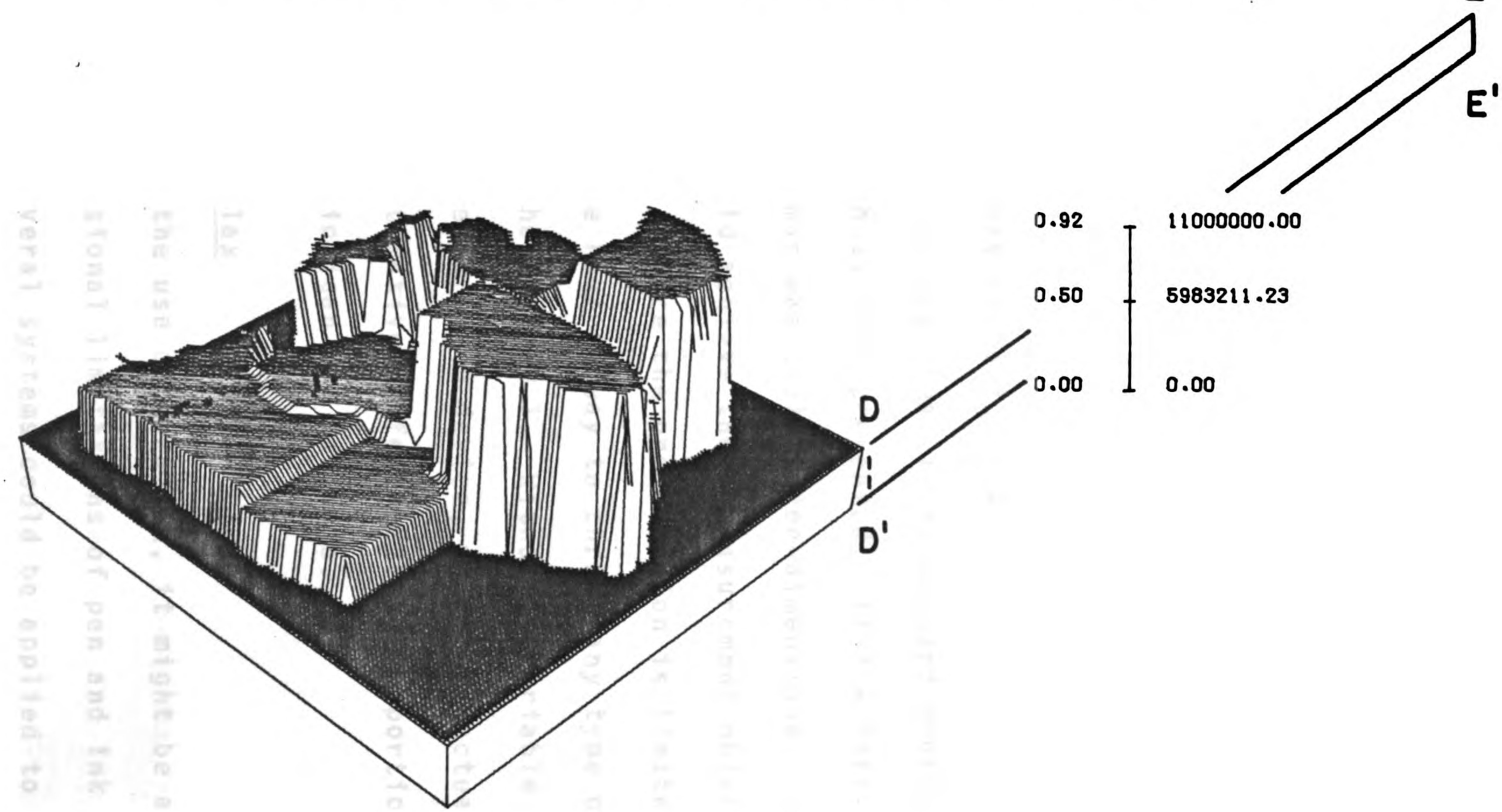
eration for realism as expressed through angular perspective, output based upon the faulty assumptions of the past has gained acceptance and legitimacy in the "three-dimensional" thematic cartography of today.

Possibilities with Computer Mapping

SYMVU, unlike some "three-dimensional" mapping programs, does have the capability of viewing a particular data set in two-point angular perspective. Unfortunately, however, since the importance of portraying three-dimensionality in a consistant and realistic manner has not been stressed by thematic cartographers, the significance of this capability of SYMVU is yet to be discovered by many. The reason for lack of popularity may be conscious rather than subconscious.

Previous reference to two-point perspective stated, in effect, that convergence of straight lines (a function of angular perspective) is applicable to the z-axis in addition to those labelled x and y. In Figure 16 extension lines have been added to the basic two-point perspective drawing to illustrate this point. Line segment D-D' is noticeably greater than line segment E-E' situated on the extension lines. While making the drawing more representative of the way in which we would actually perceive a physical three-dimensional object, the use of two-point

FIGURE 16 - TWO-POINT ANGULAR PERSPECTIVE



MIDWESTERN U.S. POPULATION --- 1970

AZIMUTH = 45 ALTITUDE = 45
*WIDTH = 4.00 *HEIGHT = 1.30

* BEFORE FORESHORTENING 05/12/75

perspective has fostered the development of an additional problem . . . . mensuration.

It may be noticed in Figure 20 that a scale has been computed and displayed. However, we must realize that the scale portrayed in this sense is virtually meaningless. Since we have empirically determined that the apparent z-axis scale is variable in relation to changes in the x and y axes, any scale used to measure this z-axis must be variable in that respect, as well.

Needless to say, that is an awkward problem for a situation such as that presented. If the "three-dimensional" map was truly three-dimensional in a physical sense, we could achieve these measurement objectives. Unforutnately, since the presentation is limited to two dimensions, we have no way to thrust any type of device "back" into the portray 1. Without a variable two-dimensional mensuration device, we cannot actually determine the quantitative difference between portion of the map such as Michigan and Illinois.

Induced Parallax

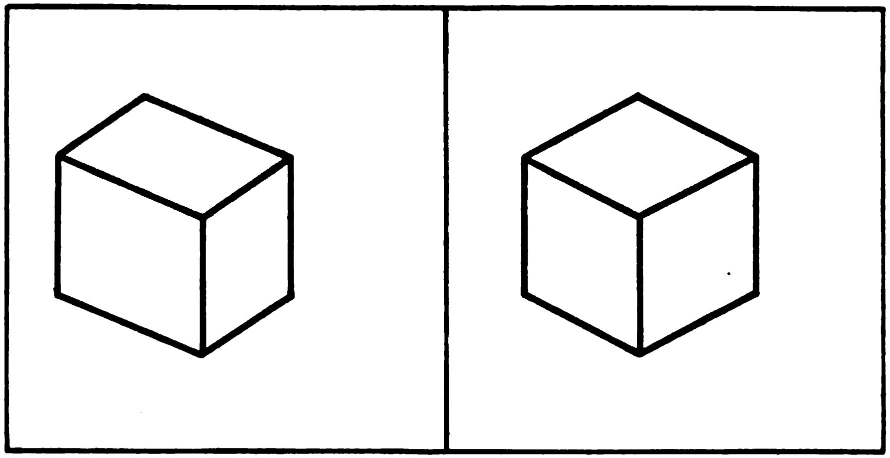
Through the use of parallax, it might be assumed that the two-dimensional limitations of pen and ink might be overcome. Several systems could be applied to the situation as possible solutions. These include the familiar blue and red lensed glasses, the horizontally and vertically oriented Poloroid lensed glasses, or the stereoscope. All work on the same fundamental principle of each eye viewing the same scene from a slightly different angle. Hence, by constructing a drawing that makes use of inducing parallax and placing it next to the original symbol, a stereopair has been formulated. Quite importantly, the viewing point displacement must be determined to be on the linear axis of the viewer's eyes.

Stereoscopic Models

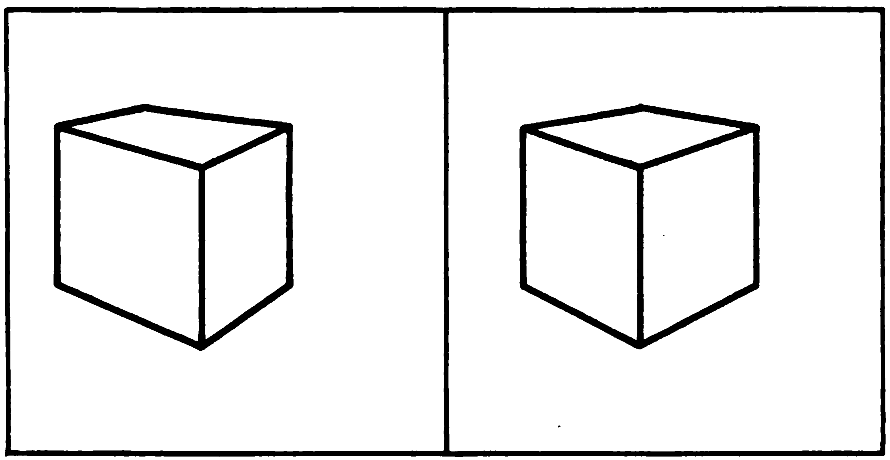
Figure 17, when viewed with a pocket stereoscope, can be used to demonstrate induced parallax in two stereomodels featuring corner views. Figure 17A is an isometric cube, while Figure 17B is a cube in two-point perspective. The inpropriety of the isometric cube as a three-dimensional symbol becomes readily apparent when parallax is induced and a stereoscope is used for viewing. Thus, the importance of two-point perspective in a corner view is extremely significant if the goal of a realistic portrayal is to be attained.

Figure 18 provides a similar stereomodeled contrast between the "block-pile" utilized by Raisz (Figure 18A) and a similar structure modified in a manner to account for one-point perspective (Figure 18B). Again, that

FIGURE 17 - STEREOGRAM: CORNER VIEW

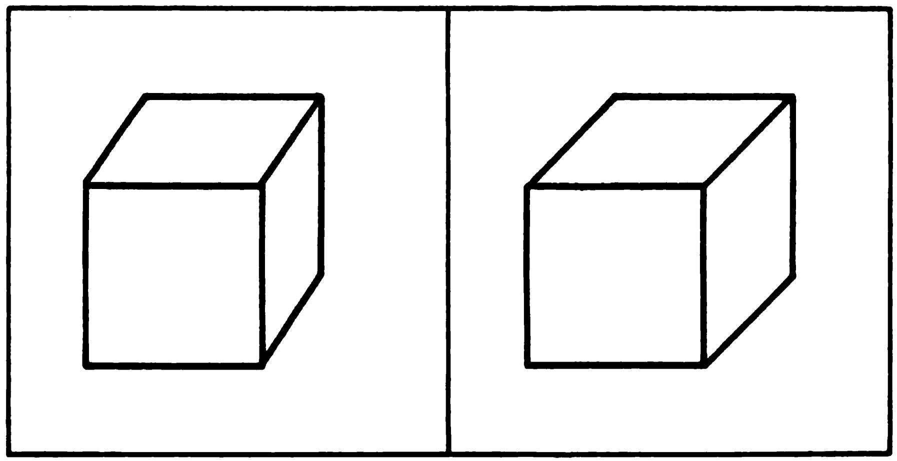


A. ISOMETRIC CUBE

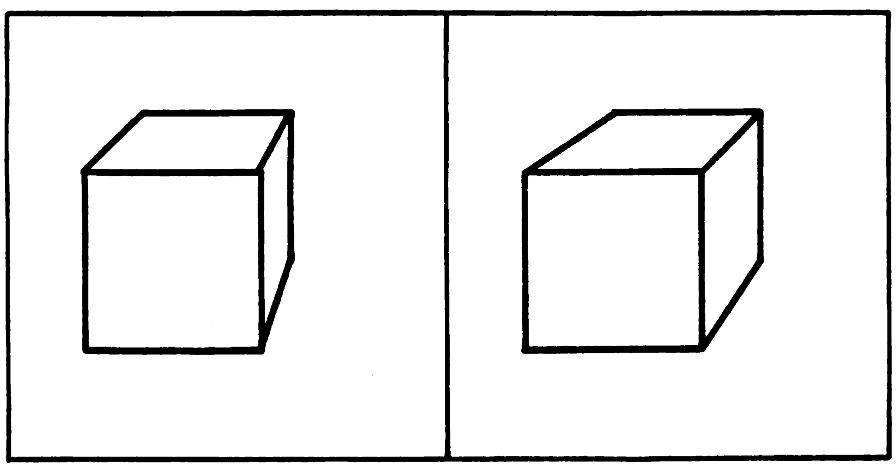


B. TWO-POINT PERSPECTIVE

FIGURE 18 - STEREOGRAM:
END VIEW



A. RAISZ'S BLOCK



B. ONE-POINT PERSPECTIVE

stereomodel incorporating angular perspective is far superior in projecting that more realistic appearance.

Inadequacies of Stereoscopic Drawings

While it does, at first glance, appear that this method offers a possible solution to our previously identified cartographic problem, the use of artificial stereoviewing is not really an adequate approach. The first problem with its use is that artificial stereo-models provide for parallax along the x-axis, only. This is quite reasonable, given the relative location of eyes upon human beings. However, this limitation very severely restricts the viewing orientation of the reader in a manner quite unlike the natural stereoviewing observed in the real three-dimensional world. Additionally, a thorough mathematical understanding and explanation of the third dimension in this artificial system is yet to be developed. LaPrade pointed out, "More than twelve equations involving different combinations of at least ten variables have been proposed."[29] The conclusion derived from this issue is that accurate three-dimensional reconstruction by this method is preseltly an impossibility.

Basic Limitations of Standard Two-Dimensional Media

The entire situation can be rendered to certain relatively basic elements. Those elements are as follow: 1) There has not yet been devised a map that exhibits all the characteristics of three dimensions, on a two-dimensional medium. 2) Therefore, so-called three-dimensional maps are actually two-dimensional maps. 3) Some of the so-called three-dimensional maps give better visual cues toward the illusion of three-dimensionality than do others, and 4) since these maps are actually two-dimensional, any measurement taking place upon these maps must be limited, therefore, to the horizontal and vertical axes of the two-dimensional medium upon which these maps appear.

Three-Dimensional Ends Using Three-Dimensional Means

The facts and conclusions stated do not mean that the realization of three-dimensional goals cannot be achieved. To date, it simply means that those goals cannot be achieved through conventional two-dimensional media. Instead, just as did the artists of the Renaissance, cartographers of today can find it possible to achieve three-dimensional ends by utilizing three-dimensional means. These means consist of constructing physical models. Interestingly enough, this suggestion is nothing new to cartographers. John Evelyn recalled an account of a terrain model of the Isle of Antibe being produced in the year 1665, according to Spooner.[30]

Three-Dimensional Perception

Three-dimensional models have been used for a variety of reasons over the years, however under cartographic considerations this use has been limited primarily to the portrayal of topography. This is probably a result of mankind's inherent awareness of the z-axis when thinking of topography. Who in our society can find himself unaware of the fact that he is walking up or down a ten degree slope when doing so? Who does not notice hills and valleys when peering from a significant vantage?

The answers are obvious. These exhibitions of awareness are fundamental perceptions to which man can relate. While it may be a little difficult for most men to perceive the spatial dimensions (x, y, and z) of a high pressure center, it is quite realistic to assume that it can actually exist in those three dimensions, none the less. Therefore, the development of models for the portrayal of an item of easy three-dimensional conceptualization is probably of greater legitimacy than is the rendering of a situation, perceived three-dimensionally, onto a two-dimensional medium.

Noma and Misulia point out the importance of relief to man. The military uses include: strategic or tactical planning, training, engineering design studies, intelligence, amphibious operations, and interrogation of prisoners of war.[31] The overriding element pervading all these examples is the three-dimensional basis of the man-land relationship. It is easier for man to perceive topography on a model than it is for him to perceive same on a two-dimensional topographic map.

The lack of perceptual identity is, then, probably the reason three-dimensional models have not been used to any degree of significance in thematic cartography. While many geographic variables are actually three-dimensional in nature, it is interesting that few are ever conceptualized, let alone mapped, by three-dimensional means. If a variable of a thematic sort is not perceived or identified as three-dimensional, it will not be portrayed in a three-dimensional manner.

Is this lack of perception in three dimensions an adequate reason for not striving toward three-dimensional goals in output? If perception is a function of our experiences, so too, are our experiences a function of our perceptions. Thusly, three-dimensional perception can only be gained through actual three-dimensional experience. In the case of geographers, this means that to understand a variable as truly spatial (all three dimensions), one must educate himself so-as-to perceive variables in three-

CHAPTER V

Holography

Background

Holography is basically "a recording and viewing process which allows reconstruction of three-dimensional images of diffuse objects."[33] It differs from photography on several counts, but most significantly on its capability to record the third dimension. Photographic methods employ the recording of light intensities in a focused image. The resulting image is two-dimensional. The production of a hologram is quite different.

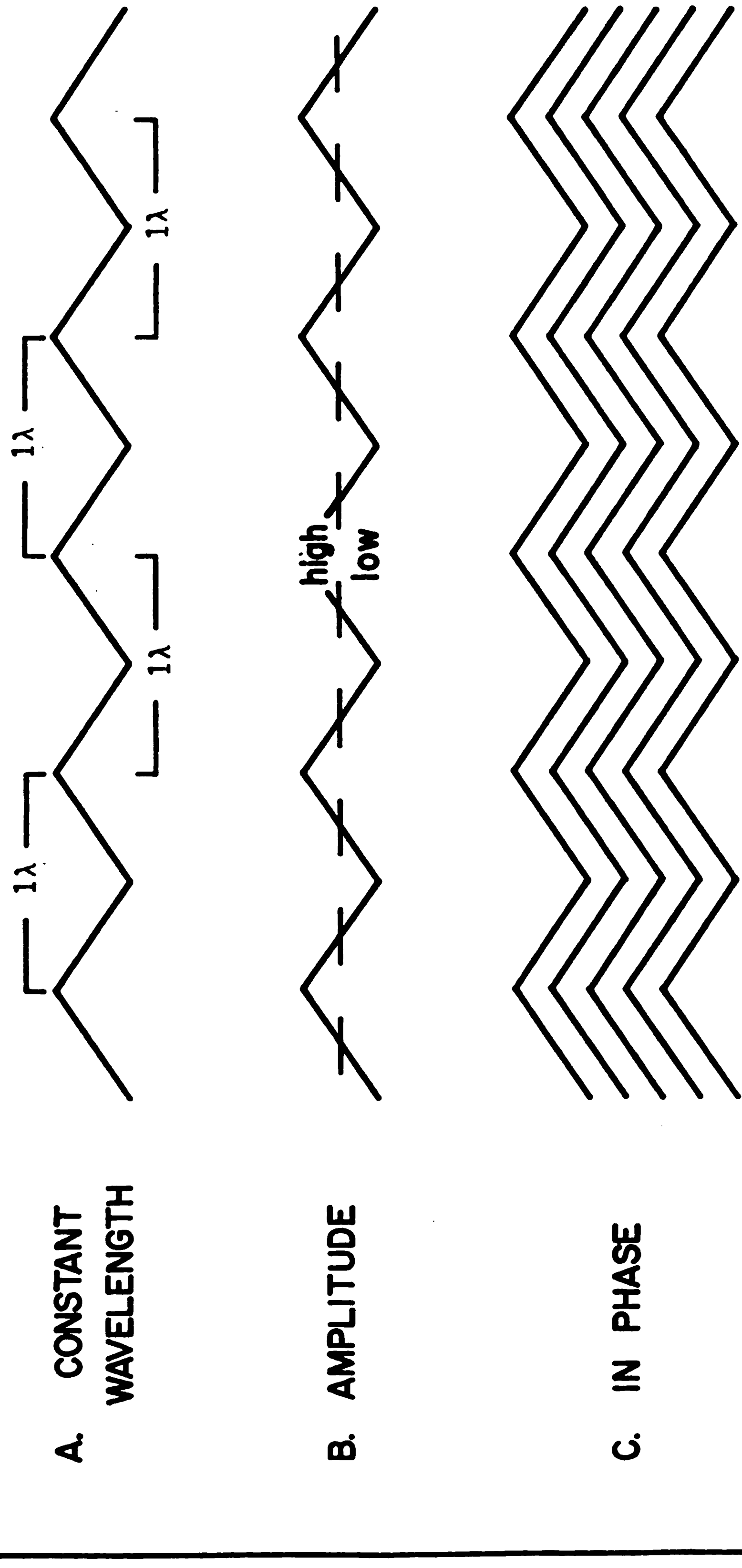
While the incubus of holography goes back to Gabor in 1943, the real development began in the early 1960's.[34] It was at this time that a suitable light source, the laser (Light Amplification by the Stimulated Emission of Radiation), became available. With this coherent light source, it became possible to record a photographic image of a complex wavefront reflecting off an object and interfering with a coherent reference beam.[35] This procedure was made known by Leith and Upatnieks in 1964 and subsequently was termed "off-axis holography".[36] Eventually, the distinguishing aspect of "off-axis" was dropped, as the form of holography known as "on-axis" has all but disappeared from practice. This has occurred primarily for practical reasons, as well as for those of safety in respect to the dangerous effects of laser light upon the human eye.

Composition

Elements

The nature of coherent laser light is shown in Figure 19. It is essentially light of constant wavelength (Figure 19A). Coherence is obtained by the additive effects of amplitude (Figure 19B) and phase (Figure 19C). The resulting light is an intense beam of emission in terms of the preceeding factors. The beam is split by means of a partial mirror known as a beam splitter. One sub-beam is then used to illuminate the object to be holographed and is consequently referred to as the object beam. The other sub-beam is caused to impinge upon the light reflected from the object toward the film plate. This impinging sub-beam is referred to as the reference beam. The interaction of the object beam and the reference beam results in an interference pattern being produced. When this occurs, certain minute portions of the film plate will receive no light

FIGURE 19 - COHERENT LIGHT



(destructive interference), while other minute portions will receive illumination (constructive interference). A simplistic drawing of coherent light interfering upon impingement at a film plate is shown in Figure 20.

Recording

In reality, the light reflected from the object does not come to the film plate as a planar wave. The light that originally illuminated the object is cast out in many directions through reflection off the object. "Every point in the surrounding space receives light simultaneously from every illuminated point on the surface of the object."[38] The resulting wavefront that reaches the film plate from the object becomes a complex wavefront. The interference pattern produced by the interaction of the complex and the plane (reference beam) wavefronts will vary throughout space. A recording of any cross-section of this pattern can then be obtained by introducing a film plate at any location in the interference zone. (See Figure 20.)

The interference fringes are generally in the neighborhood of 2000 per millimeter when utilizing a helium-neon laser with an output wavelength of approximately 6328 Å. Consequently, it is important to realize the elements that are essential to this high degree of resolution. The first requirement is that of photographic material

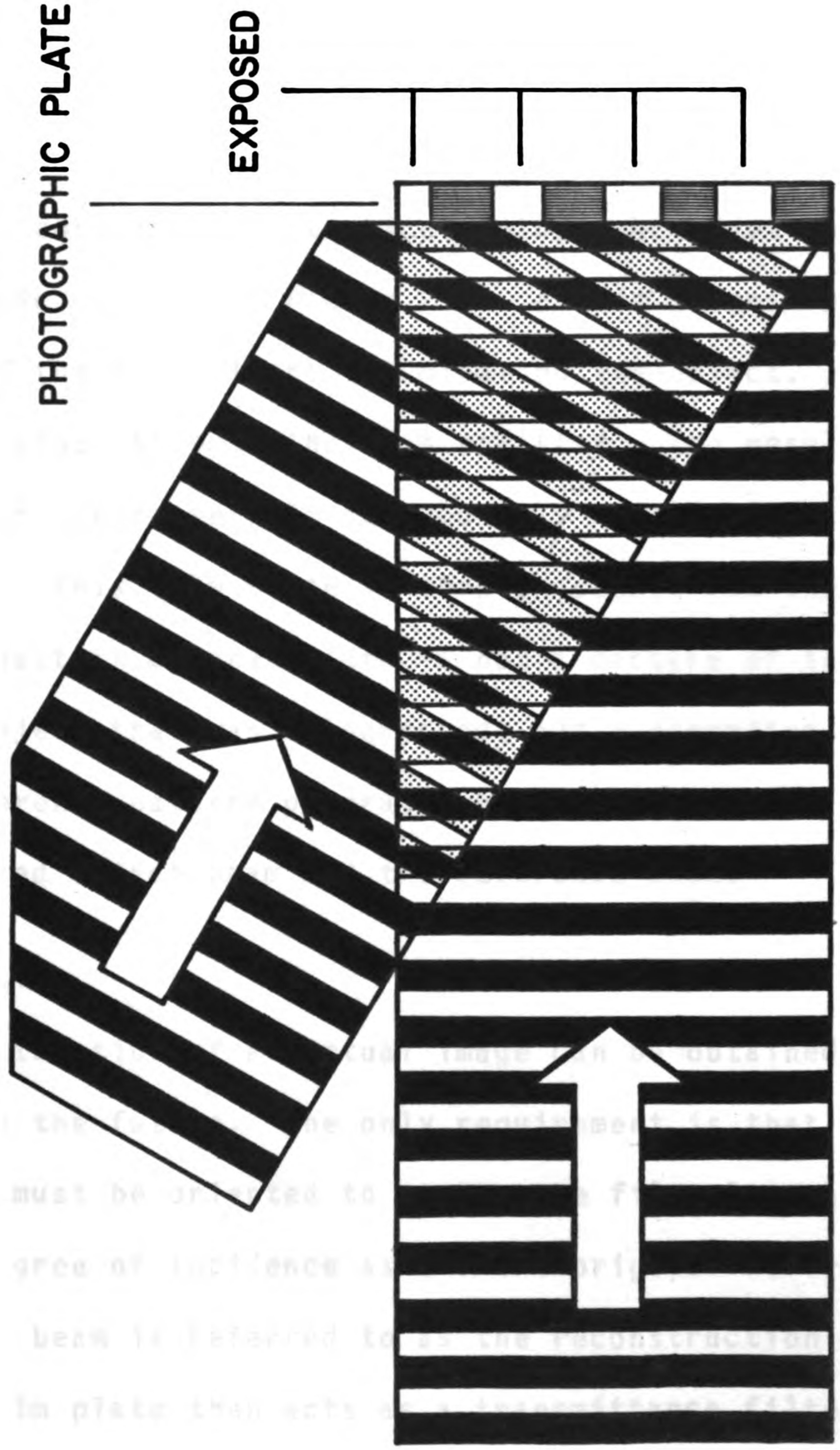


FIGURE 20 - RESULTANT INTERFERENCE PATTERN

capable of this fine resolution. The second is a mechanical stability of all aspects of the optical system in which movement may not exceed one eigth the wavelength of the light source.[39]

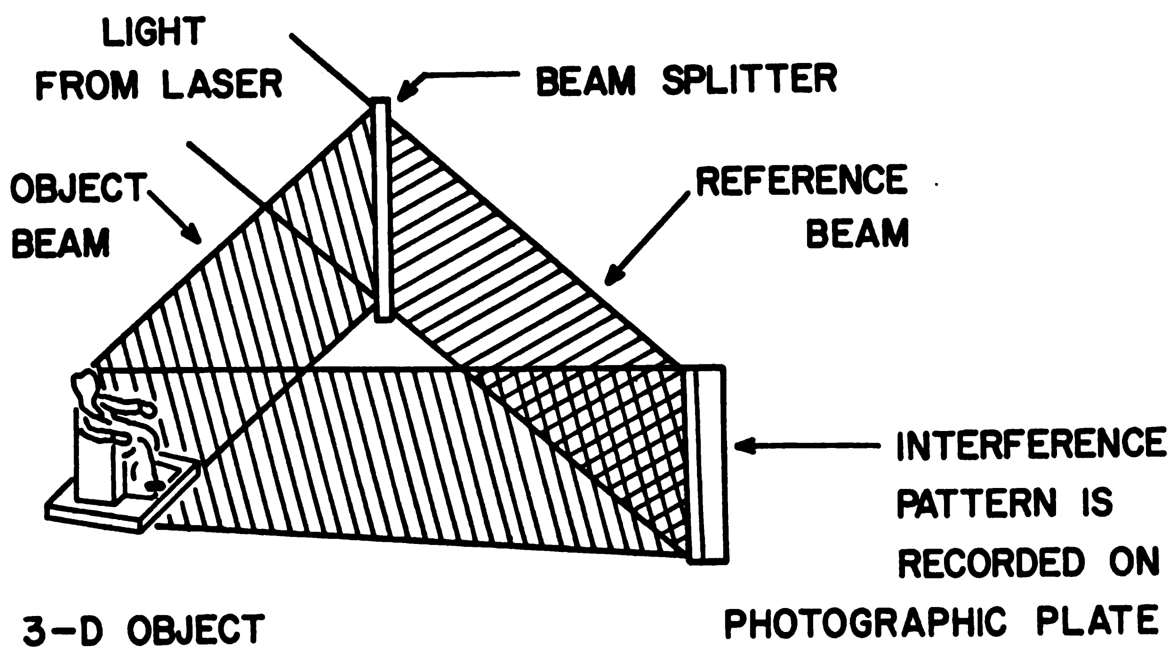
With the preceeding aspects clearly in mind, it is possible to portray a hypothetical holographic "set-up" in the schematic diagram of Figure 21. In this diagram we see some of the laser light illuminating the object. The remainder passes through the beam splitter. The resulting interference pattern is subsequently recorded at the film plate. This film plate is then processed and the resultant pattern on that plate is not a picture of the scene or object that was holographed, but a recording of the interference pattern generated by the interaction of the reflected object beam and the reference beam.

Reconstruction

Reconstruction of a virtual image can be obtained at any time in the future. The only requirement is that a laser beam must be oriented to strike the film plate at the same degree of incidence as did the original reference beam. This beam is referred to as the reconstruction beam.

The film plate then acts as a transmittance filter. Since its processing, that plate has retained dark spots where destructive interference took place, and remains

FIGURE 21 - HOLOGRAPHIC RECORDING



clear where constructive interference occurred. These light and dark spots (a fraction the wavelength of the light source) then serve as a transmittance filter to the reconstruction beam. The "flow" of light travelling in the reconstruction beam is therefore attenuated at the film plate. The result of this action is the construction of a virtual image of the original object or scene. Figure 22 illustrates this aforementioned reconstruction arrangement.

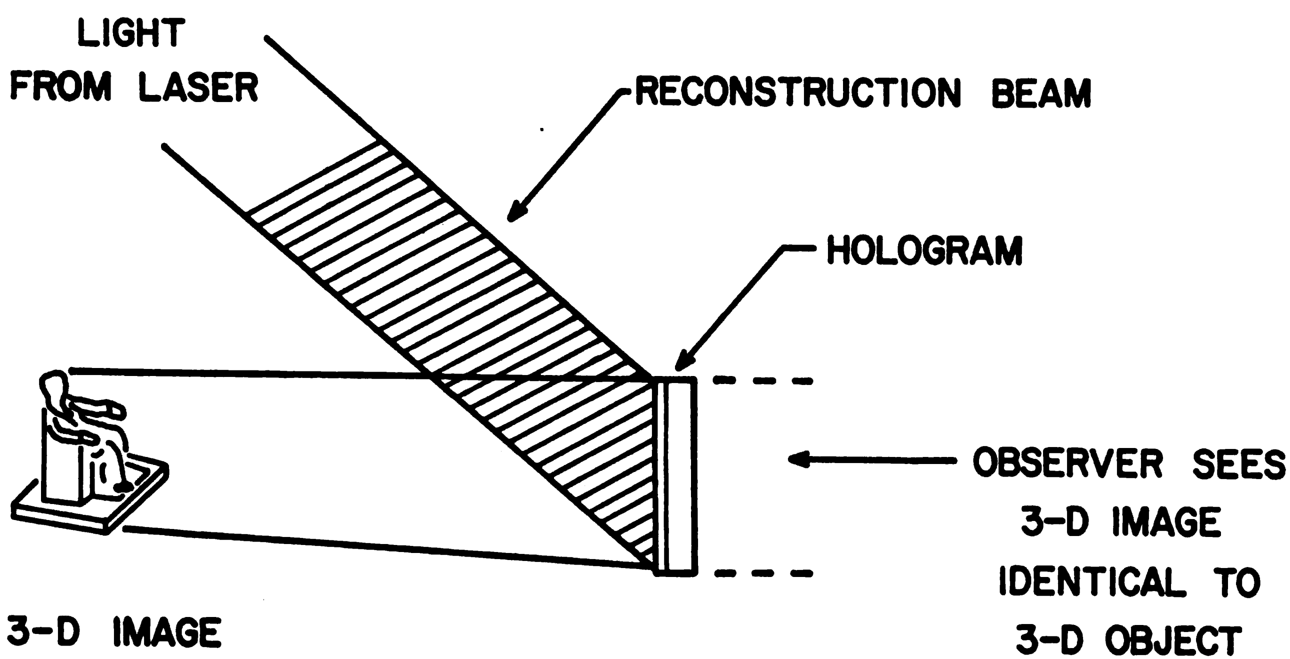
The most amazing point about this reconstructed image is the fact that it is virtually indistinguishable from the original scene or object. It appears to be the same distance from the film plate as was the original and has the same reflected light intensities as did the original. Furthermore, it has all the same apparent dimensions as did the original, the inclusion of the x, y, and z axes notwithstanding.

Production of Holograms

Model

Owing to the fact that a three-dimensional scene of a cartographic nature was necessary for the production of subsequent holograms, one was built specifically for this purpose. The subject and areal scope of the model was population figures for the respective midwestern United States.

FIGURE 22 - HOLOGRAPHIC RECONSTRUCTION



These data for both the years of 1910 and 1970 were taken from the 1960 and 1970 Census of Population, Number of Inhabitants, United States Summary, respectively. The base map to which these statistics were applied was derived from a polyconic projection of the United States of America, published in the Hammond Comparative World Atlas.

The population figures for the States of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, and Iowa were then "rounded off" to the nearest one-half million persons for the years of 1910 and 1970. These figures appear in Table I. The block-pile nature of the model prescribed the use of one cardboard layer equalling a certain amount of population. This was set at each layer equalling one-half million people. Table II illustrates the number of cardboard layers necessary to achieve the derived populations of each State in both the years of 1910 and 1970.

Each cardboard layer was approximately one-sixteenth of an inch in thickness. Consequently, the most populous State, Illinois, was determined to rise no more than one and three-eighths of an inch off the model surface. This surface consisted of one-eighth inch drawing board (cardboard) that held equal x and y dimensions of fifteen inches. The surface of this board was air-brushed with a mottled composition of purple, brown, red, and green inks in a

Table I

Midwestern United States' Population to the Nearest One-Half Million Persons: 1910 and 1970.

(times one million)

	1910	1970
Ohio	4.5	10.5
Indiana	2.5	5.0
Illinois	5.5	11.0
Michigan	3.0	9.0
Wisconsin	2.5	4.5
Minnesota	2.0	4.0
Iowa	2.0	3.0

Table II

Necessary Number of Cardboard Layers to Represent Midwestern United States' Population in the Years 1910 and 1970 on the Model.

	1910	1970
Ohio	9	21
Indiana	5	10
Illinois	11	22
Michigan	6	18
Wisconsin	5	9
Minnesota	4	8
Iowa	4	6

manner that produced an overall gray tone which provided contrast with the cut-out layers of the States. These cut-out layers all had a white surface, while edges on the z-axis were alternately shaded black and white.

Three-dimensional alphabetic characters were used for appropriate wording on the structure. This consisted of the title, "Midwestern U.S. Population", the appropriate year of representation, and a legend, "Each Layer Equals 1/2 Million People". These characters were three-quarters of an inch on the y-axis, one-eighth of an inch on the z-axis, and variable from three-thirtysecondths to one-half of an inch on the x-axis.

A wooden carriage was designed and constructed to suspend the model's z-plane at thirty degrees off the horizon. This would, in effect, result in any photography or holography conducted along a plane parallel to the horizon being elevated thirty degrees off the horizon. This particular observation altitude was chosen to provide the maximum amount of interpretation along the z-axis, while still allowing adequate cartographic assessment along the x-axis and, particularly, the y-axis.

Instrumentation

The holographic recording instrumentation was mounted on a cast iron milling bench. This bench was supported by a wooden framework that "floated" upon air bags to reduce any possible detrimental vibrational effects in the superstructure of the building. These items are shown in Figure 23.

All instrumentation was placed upon the top of the milling bench. This instrumentaion consisted of one Jodon HN-20 laser (helium-neon), one shutter and cable release mechanism, one variable beam splitter, five mirrors, two spatial filters, one film plate holder, and a necessary number of black screens to minimize stray light in the system. The arrangement of these items with the model in place is shown in Figure 24.

Operating Parameters

Several operating parameters were observed during the actual holographic recording sessions. Generally speaking, they were as follow:

1) All recording was conducted at night when building vibration and other possible disturbances could be minimized

2) Object and Reference beam pathlengths were equalized

3) One and one-half hour warm-up periods were allowed for laser mode stabalization

4) Variable beam splitter was adjusted to produce a reference beam to object beam intensity ratio of two or three to one

Figure 23 - Air Cushioned Holographic Work Platform

Figure 23

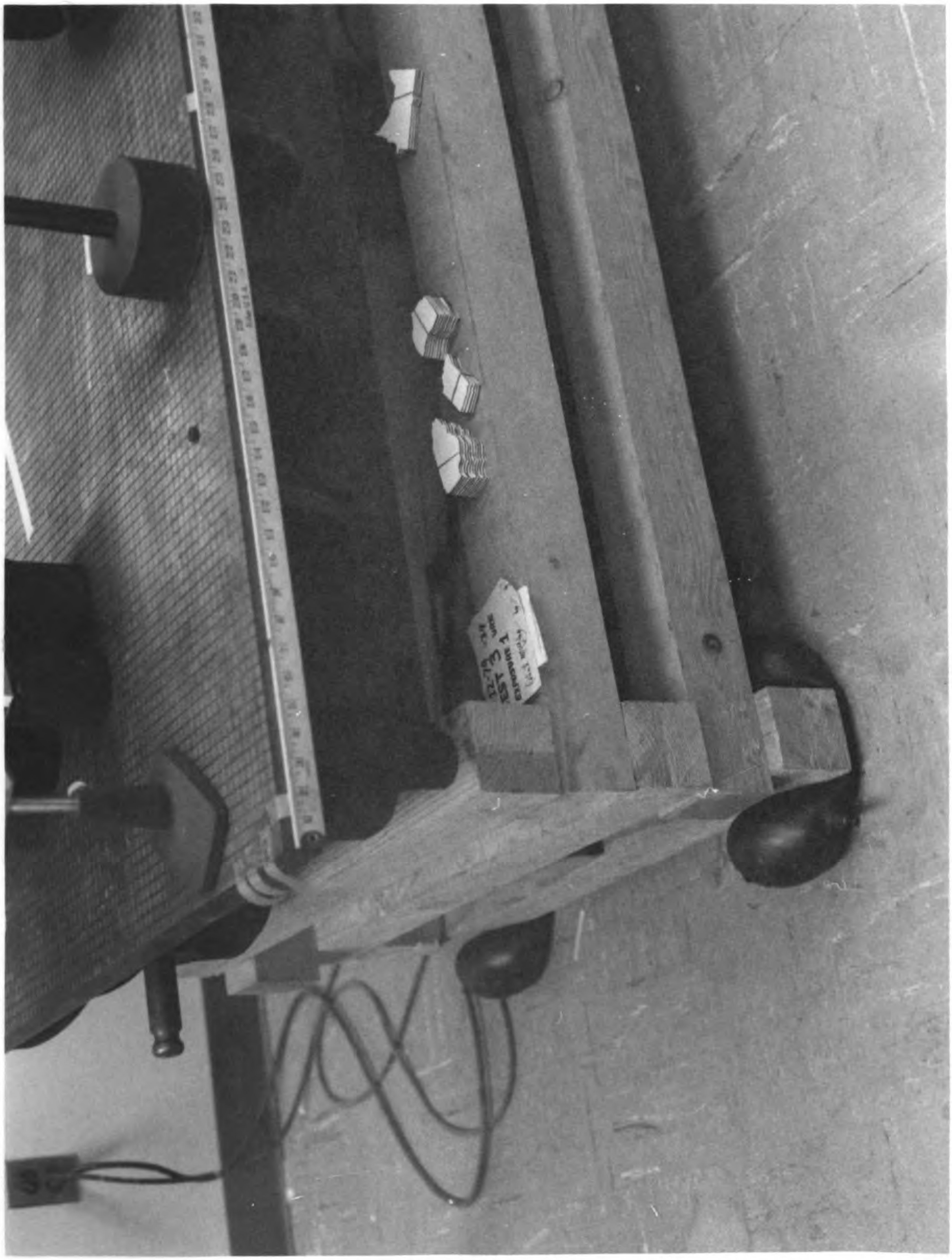
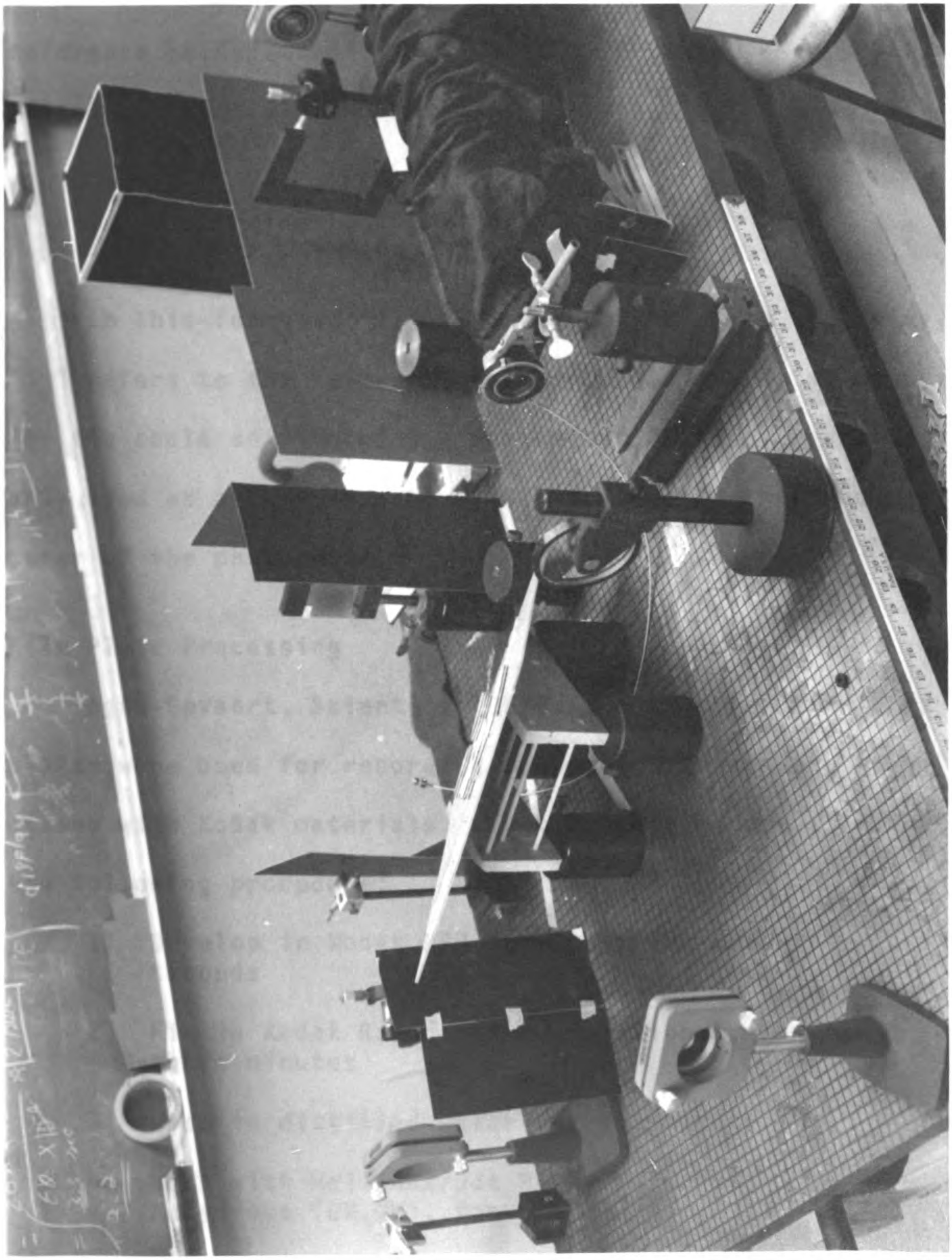


Figure 24 - Holographic Recording Equipment

Figure 24



Exposure Time

Exposure time was calculated from the object beam and reference beam intensities. These intensities were submitted to the following formula:

$$\frac{.02}{(I_o + I_r)\ 10^{-s}}$$

In this formula, "I_o" signifies object beam intensity, "I_r" refers to the reference beam intensity, and "s" stands for the scale setting of the photometer. This formula was only used as a very "rough" guide provided by the manufacturer of the photometer.

Film Plate Processing

Agfa-Gevaert, Scientia, 10E75, two by three inch photo plates were used for recording purposes. These were processed with Kodak materials. That processing consisted of the following procedure:

1) Develop in Kodak HPR Developer for seventy seconds

2) Fix in Kodak Rapid Fixer, Solution A, for three minutes

3) Wash in distilled water for one minute

4) Wash with Mallinckrudt Methyl Alcohol, Anhydrous (CH_3OH), for one minute

5) Allow to air dry for one or two minutes

Reconstruction of Holographic Image

Procedure

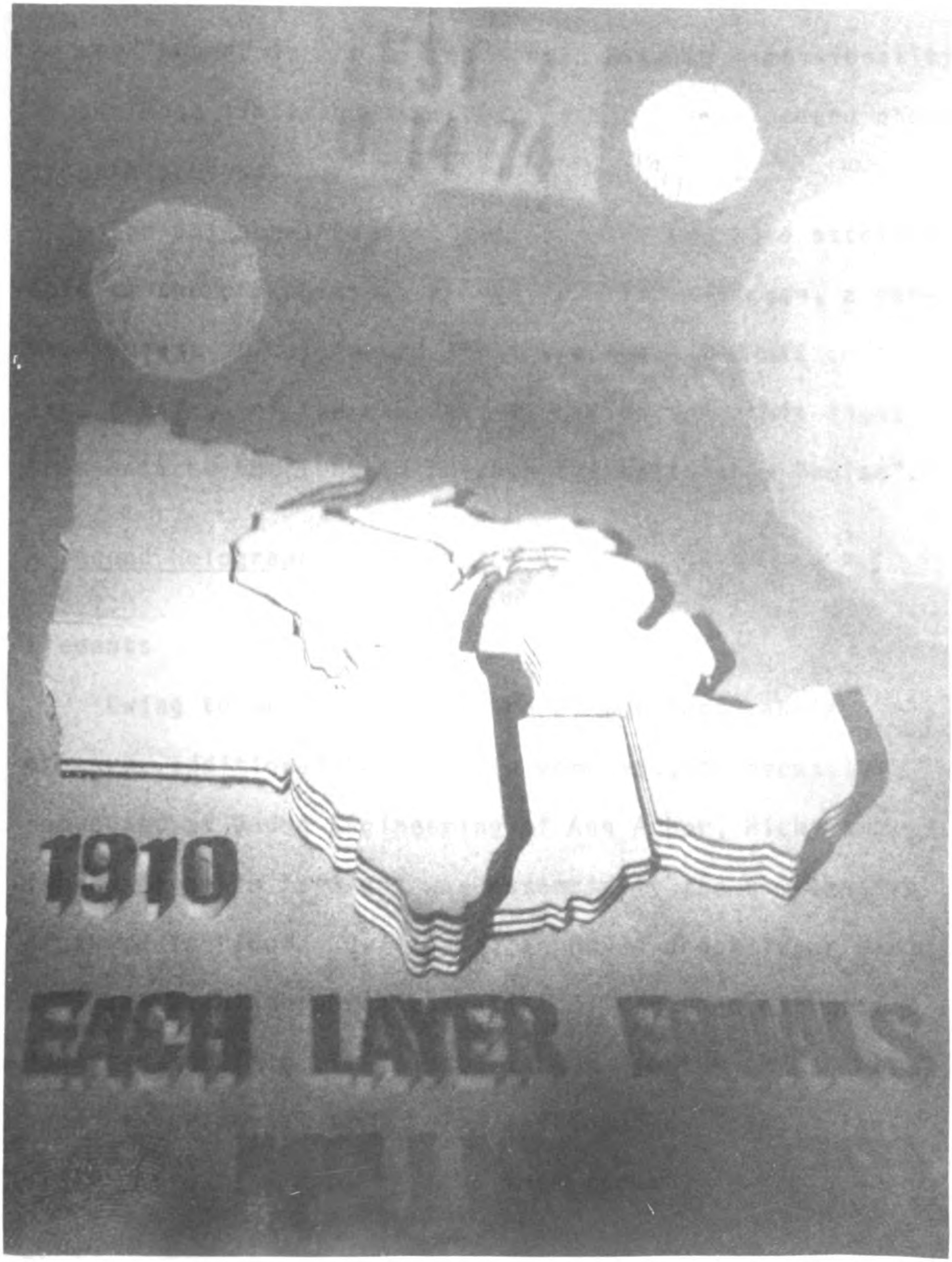
Reconstruction took place by reinserting the processed plate into the plate holder and adjusting the beam splitter to conduct all light through the reference beam (which is then considered the reconstruction beam) pathway. The model was either summarily removed from position or a black screen placed between it and the film plate. The resulting view through the holographic plate was identical to the original diffusely illuminated object from which the hologram had been produced. The preceeding description applies to work conducted in Room 254, Engineering Building, Michigan State University.

Photographic Limitations

Figure 25 is a photograph of the holographically reconstructed image derived through the previously mentioned process. The reconstructed image was photographed with Poloroid Type 57 film using a bellow camera equipped with a 135 millimeter lens. This photographic record of a holographically recorded image is somewhat misleading, though, since the photographic process is limited to two-dimensional results. Consequently, the three-dimensional quality of the work is lost. This photograph can do no

Figure 25 - Photographed Holographically
Reconstructed Image

Figure 25



more justice to the three-dimensionality of the reconstructed image than could a photo of the original model. We are "bound" in the nature of our display dimensionality by the most limiting characteristics of the standard photographic process.

The polygonal "spots" in the photo are also attributable to the photographic procedure. In this case, a certain amount of collimated light was reflected off certain lens fittings of the camera. By reflection, this light then entered the lens to produce the noticeable "noise".

A Second Holographic "Set-Up"

Elements

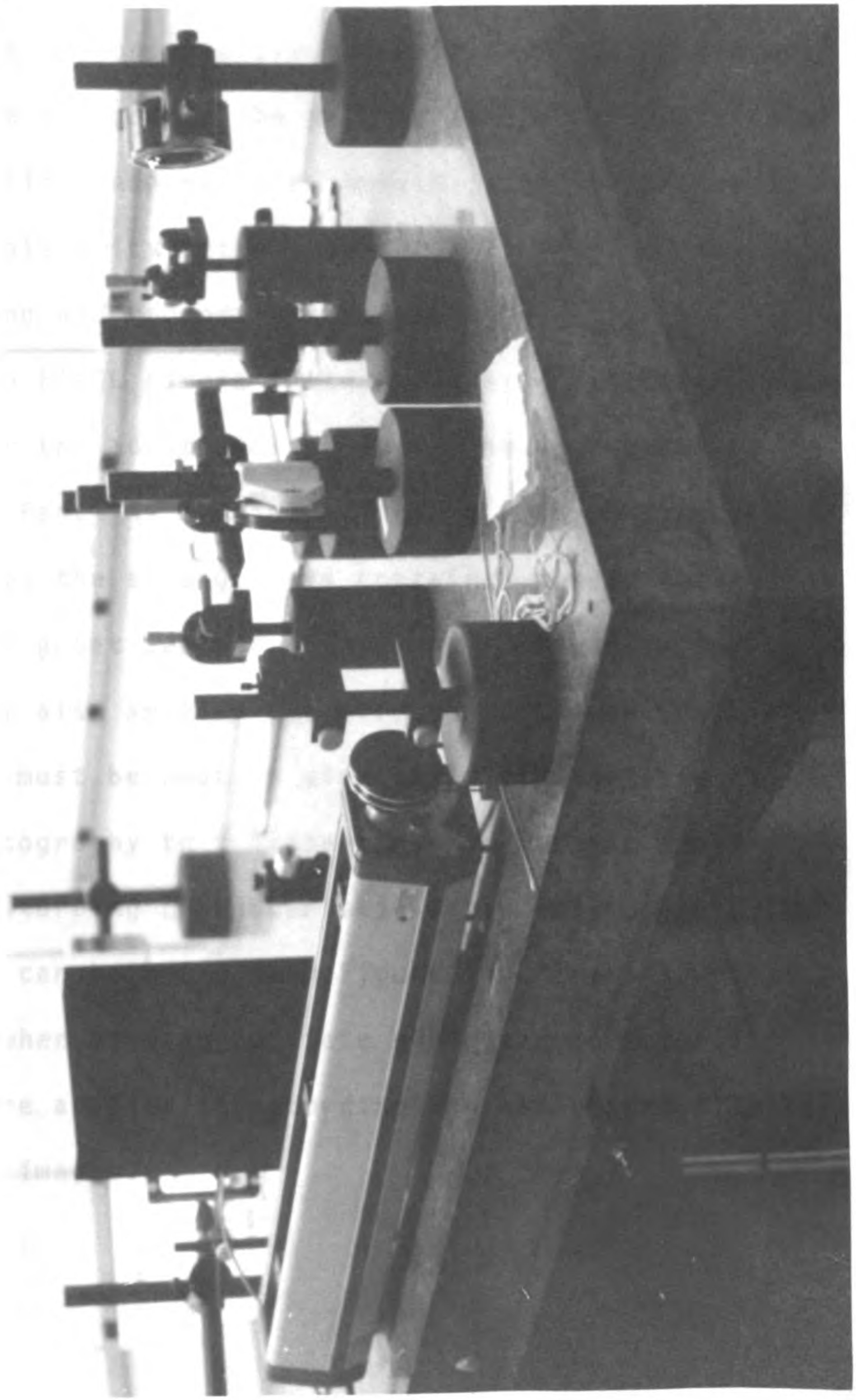
Owing to mechanical failure at the East Lansing laboratory, additional holographic work was, of necessity, conducted at Jodon Engineering of Ann Arbor, Michigan. The holographic "set-up" was essentially the same and is pictured in Figure 26. Again, an HN-20 Jodon laser was utilized with appropriate spatial filters and mirrors. However, the film plates used in Ann Arbor were a high speed experimental type being developed by Kodak. These plates were of a four by five inch format.

Photography

Subsequent photography of the holographically recon-

Figure 26 - Secondary Holographic Recording "Set-Up"

Figure 26



structed images derived from the Ann Arbor holographic recording session took place at the Michigan State University facility. Consequently, a certain degree of distortion will be noticed in the subsequent photographs of the holographically reconstructed images. The distortion is due to the disparity between the optical systems used in the recording and reconstruction sessions.

A Canon FT-QL camera fitted with a 50 millimeter lens was used for the additional photos. The film type was Kodak Tri-X Pan. As a result of using a 35 millimeter ASA 400 film, the enlargements contained herein will be subject to a great deal of graininess. The enlarging process will also amplify the effects of "laser speckle". However, it must be kept in mind while viewing this subsequent photography th t "laser speckle" is not necessarily a disturbing characteristic of actual reconstructed images. As can be noted from Figure 25, "laser speckle" is negligible when more appropriate photographic recording processes are applied to recording the holographically reconstructed images.

CHAPTER VI

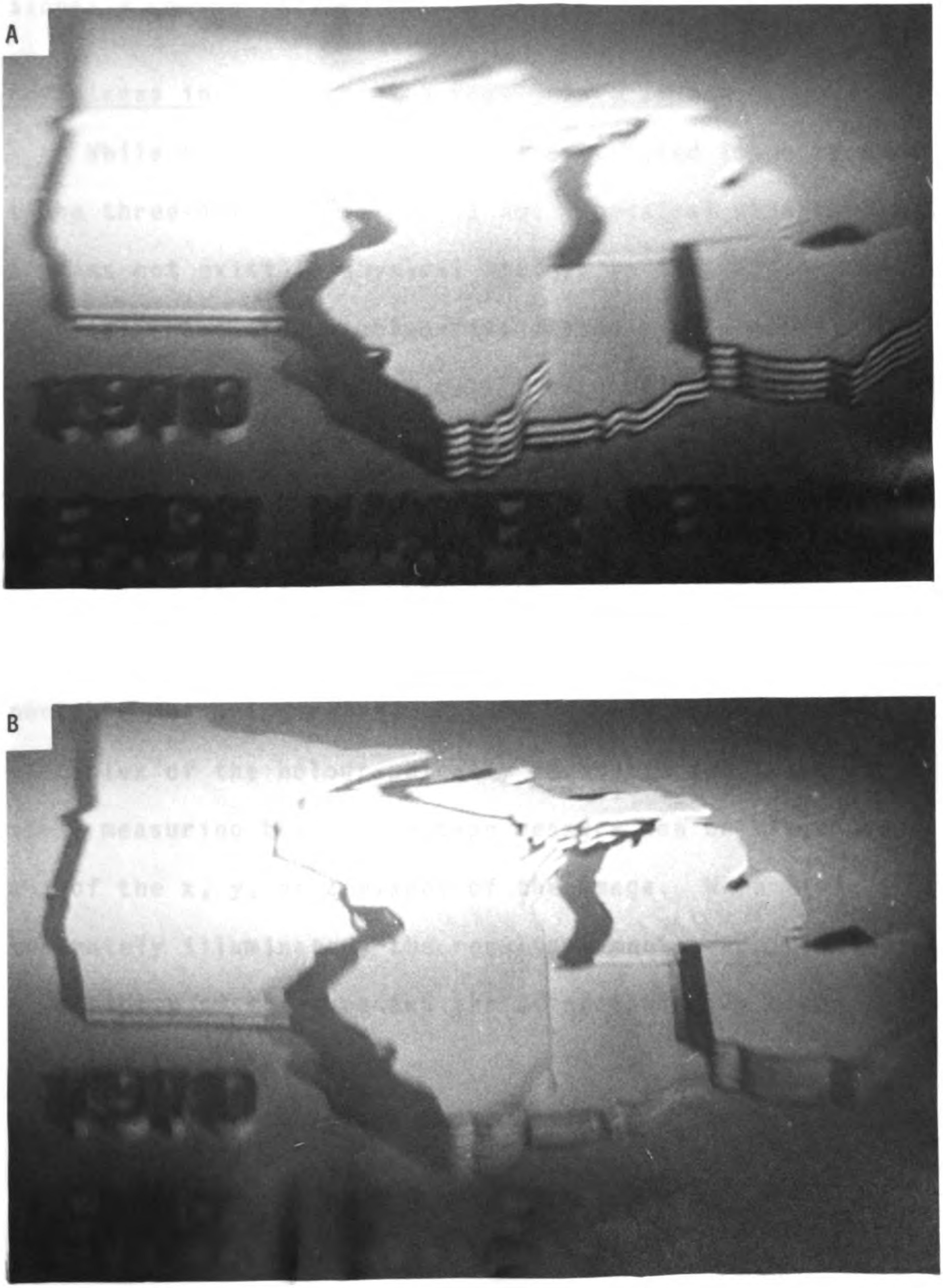
Findings of Qualitative Analysis of Holographically Reconstructed Images

"Proof" of Three-Dimensionality

The holographically reconstructed images are three-dimensional by definition of the process. However, to illustrate this point, Figure 27A and B show that the three-dimensionality can be sensed by the camera in an indirect manner. The photographic depth of field was limited purposely to sense this aspect. Figure 27A finds the "close" portion of the photo in focus. The "far" portion of the photo is blurred and out of focus. By refocusing the camera upon the "far" part of the holographically reconstructed image, the "close" portion is then caused to be out of focus, as shown in Figure 27B. The resulting inference from this episode is that by utilizing the focusing properties of conventional optics, we can additionally verify the three-dimensional nature of holographically reconstructed images of a holographed three-dimensional model. Drawing upon the actual three-

Figure 27 - Photographic Evidence of Depth in a Holographically Reconstructed Image

Figure 27



dimensional character of the imagery, we can also say that the product will exhibit angular perspective and be dimensionally consistent, as well.

Advantages in Image Lacking Physical Existence

While the holographically reconstructed image appears to be three-dimensional, it is not a physical object. Thus, it does not exist in physical space. By not existing in physical space, the problems associated with a model existent in physical space are nullified. Weight, storage, and physical degradation due to the effects of time are all nonexistent with the holographically reconstructed image.

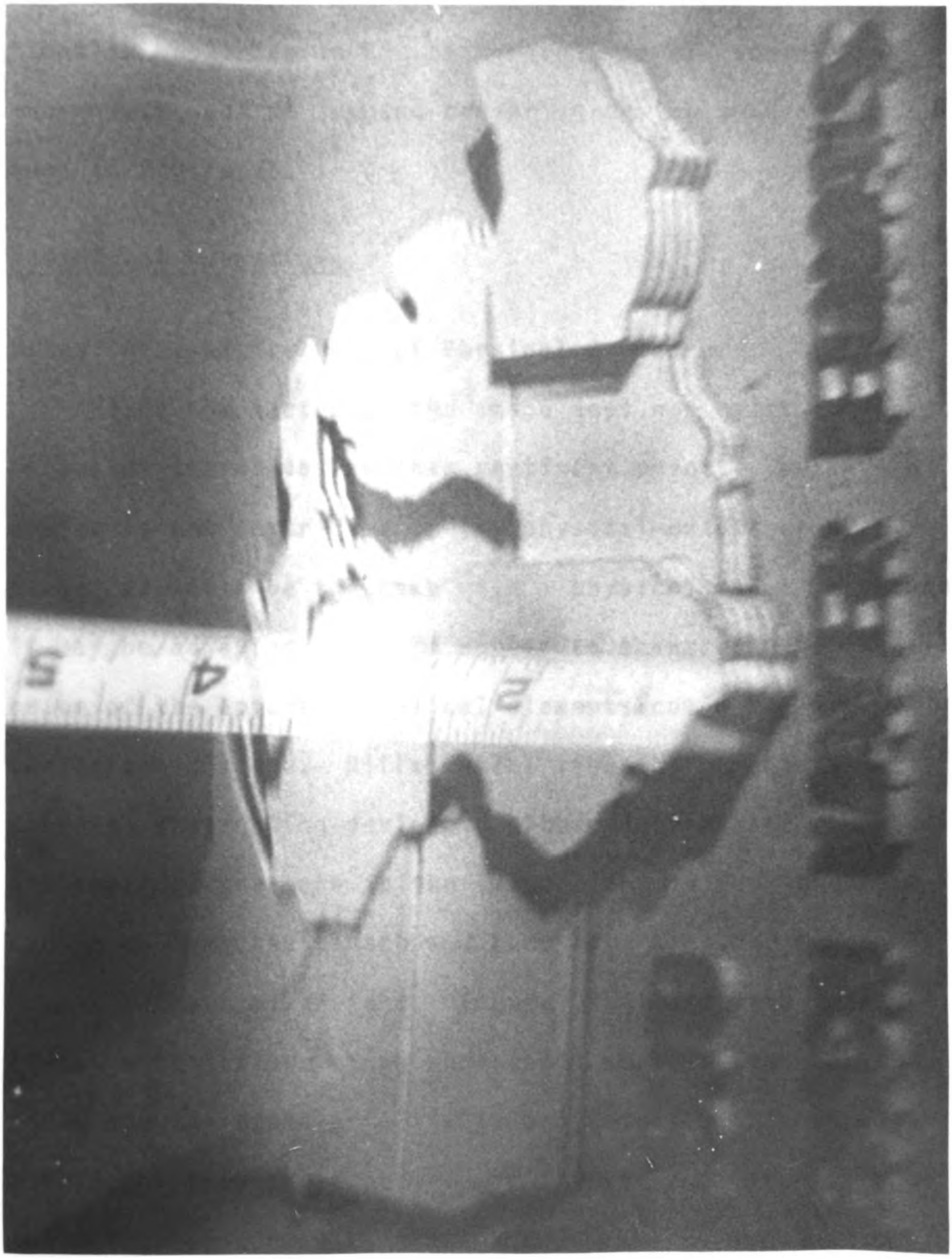
Mensuration in All Three Dimensions

Mensuration in a hologram is easily accomplished with portable measuring rules. Figure 28 is a photographic multiplex of the holographically reconstructed image and a steel measuring tape. The tape measure can be placed in any of the x, y, or z planes of the image. When it is separately illuminated, the resultant photograph will be a multiplex of the tape and the holographically reconstructed image.

Unlike the two-point perspective computer map's scaling device, this measure (or scale) will adhere to the distance-size relationship inherent with linear placement

Figure 28 - Photographically Multiplexed Holographically Reconstructed Image and a Steel Measuring Tape

Figure 28



on any given plane in the image. As the apparent size of Michigan's northern peninsula would, for example, appear "smaller" by being in the background, so to, would the increments upon an imposed measuring device such as that used in Figure 28.

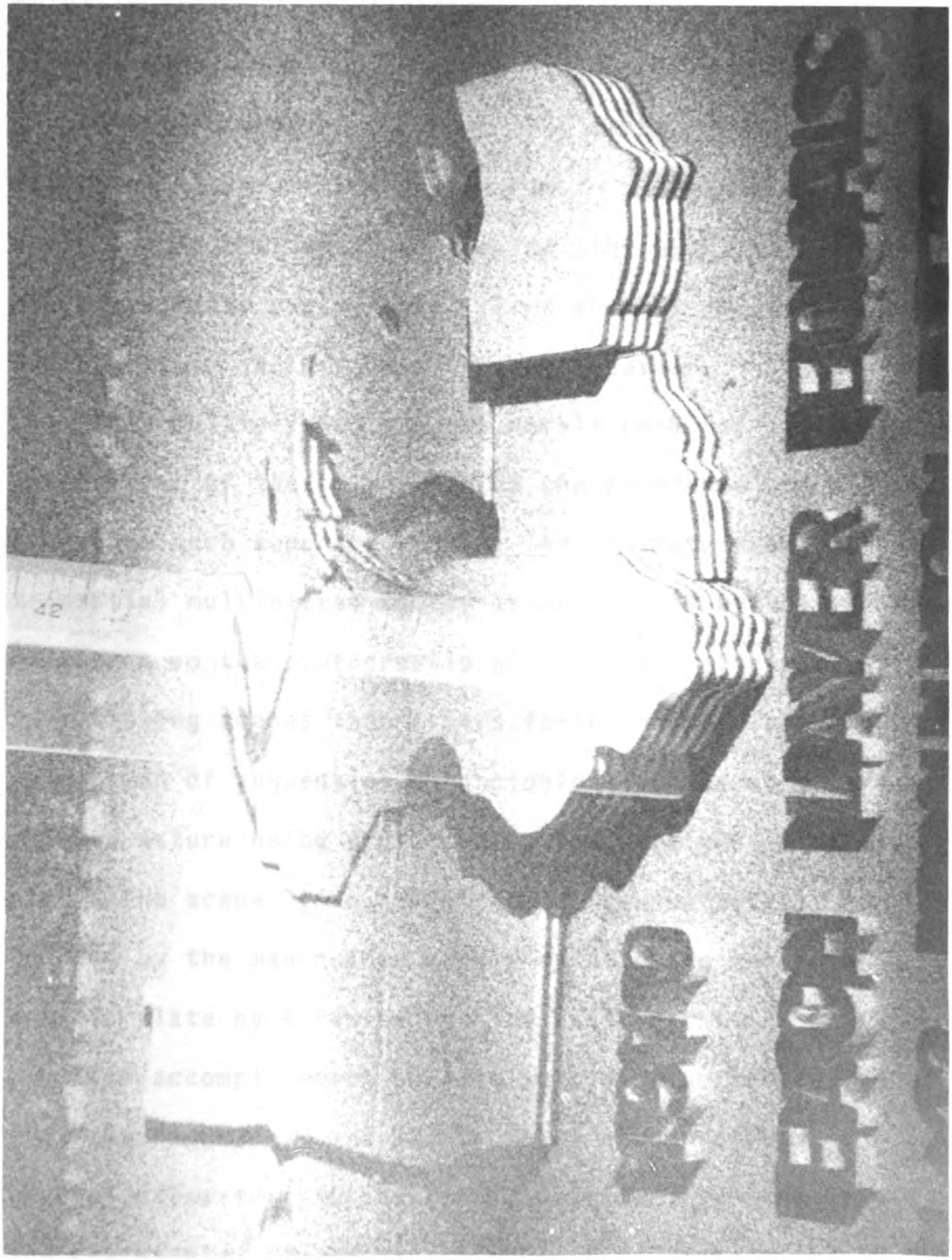
Additional Advantages

Nonexistent Limitations of Physical Presence

Given the fact that the image does not exist in space, this also introduces another pertinent point. The ruling device is not restricted by the physical existence of the image, as would be the case with a physical model. Instead, it may be adjusted so-as-to appear to transcend the boundaries of the apparent physical elements composing the cartographic scene. Differential lighting can be administered to the scaling device to either increase or decrease its apparent presence in the image plane in much the same manner as does the Bausch and Lomb Zoom Transfer Scope accomplish a similar feat. Figure 29 illustrates this effect with the use of an engineer's scale. Note how the scale and the State of Illinois are actually locationally infringent upon one another. Of course, this attribute of the holographic display system could also be applied to measurement on the x and y axes as well.

Figure 29 - Photographically Multiplexed Holographically Reconstructed Image and an Engineer's Scale

Figure 29



Multiplexing of Scenes

An additional advantage provided by holography is the mutually exclusive multiplexing of images.[40] This, in effect, means that two, three, or greater numbers of scenes can be holographed on the same film plate. When reconstruction occurs, these images remain independent of each other and do not appear as the familiar multiple exposure of conventional photography. Each scene's image is separate, clear, and distinct from one another.

This multiplexing process merely requires differential orientation of the film plate to the reference and object beams for each separate scene. The ultimate number of sequential multiplexed scenes is determined by the emulsion thickness on the photographic plate. This attribute of multiplexing scenes then ushers forth the possible consideration of sequential chronological scenes of a cartographic nature being presented on the same medium of display. The scene "time shift" would then be totally controlled by the map reader merely by altering the holographic plate by a few degrees of axial rotation.

The accomplishment of this multiplexing process is shown in Figures 30 and 31, in which the population of several midwestern States in the years of 1910 and 1970 are represented, respectively. Of these figures, photo A

Figure 30 - Midwestern U.S. Population in 1910

Figure 30

A

B

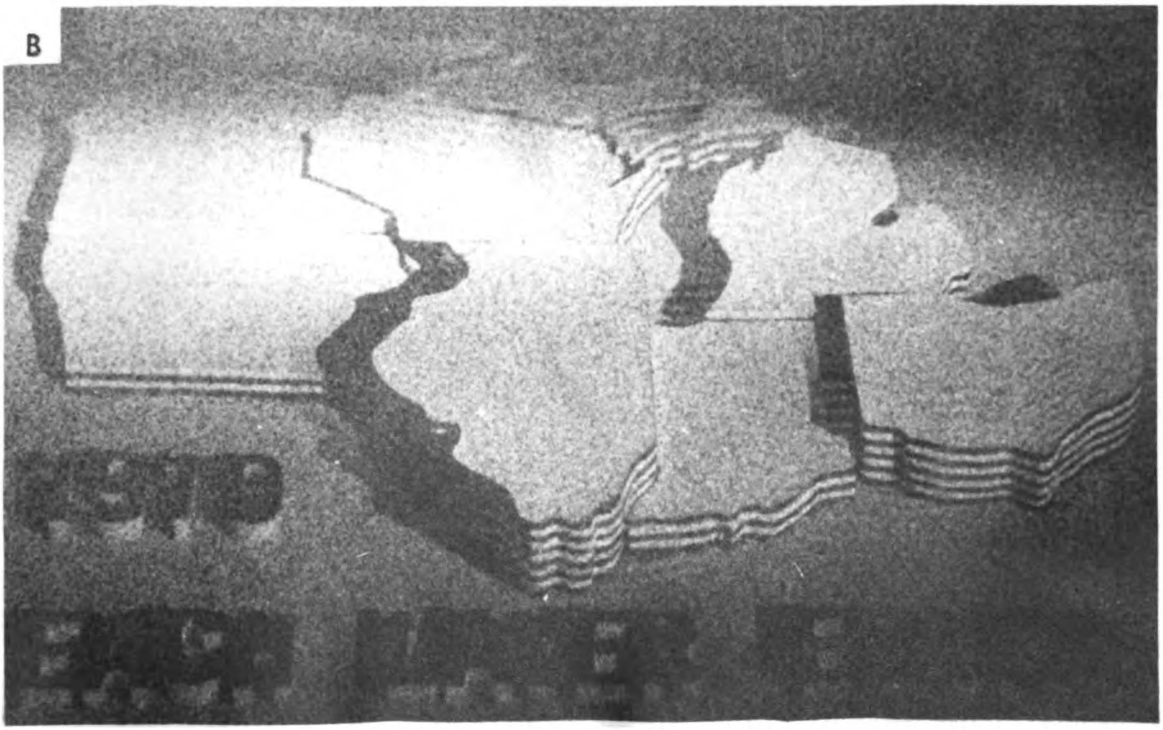
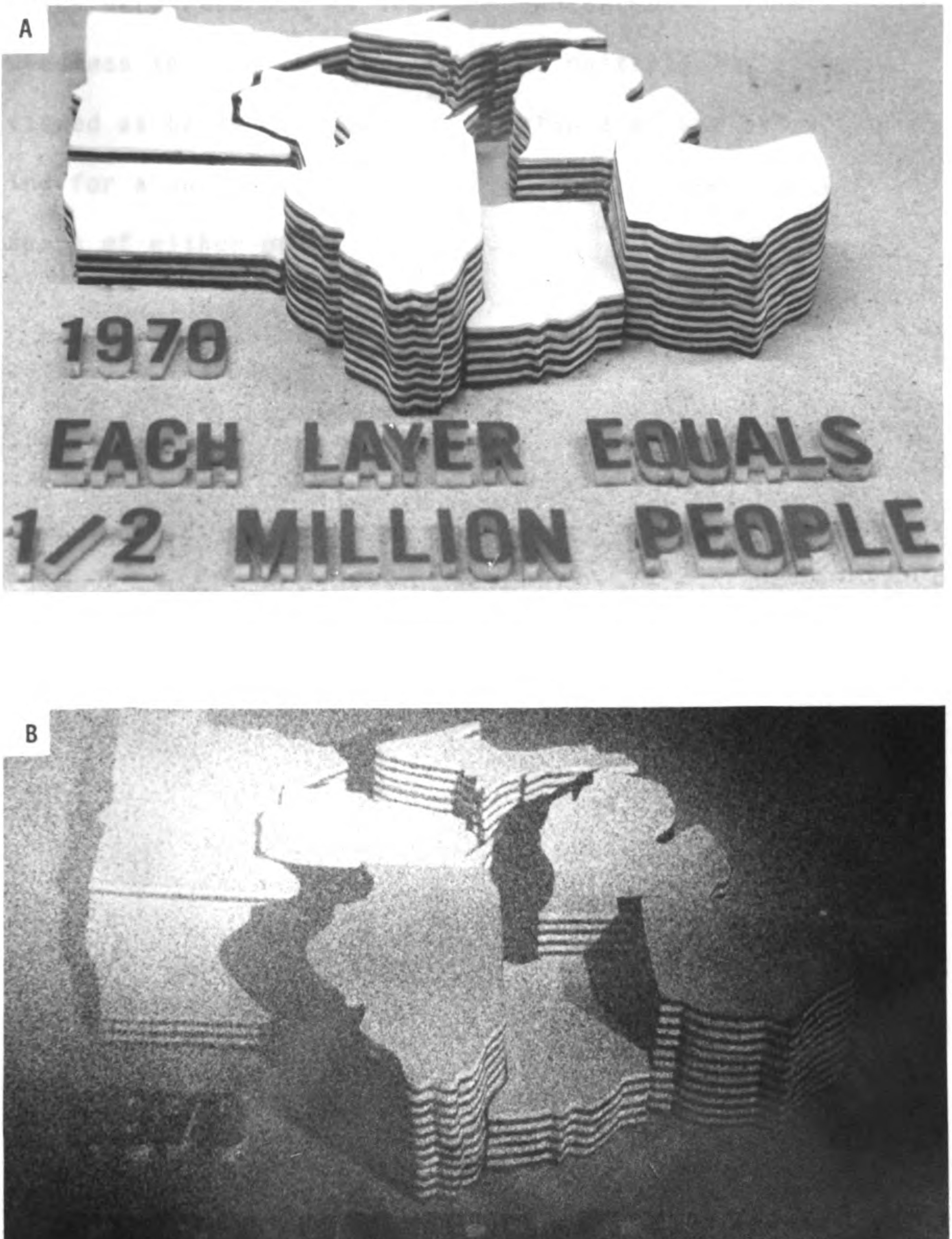


Figure 31 - Midwestern U.S. Population in 1970

Figure 31



in each case is of the original model. Photos B are of holographically reconstructed multiplexed images, both of which were recorded on the same photographic plate. Perhaps needless to say, the usefulness of multiplexing could be viewed as being of economic importance a well as accounting for a possible decreased need for physical storage space of either models or maps.

CHAPTER VII

Conclusion

Thematic cartographers, over the last fifty years, have attempted to incorporate the use of the third dimension in the product output of their field. Early attempts were inadequate by today's standards owing to perceptual and portrayed dimensional inconsistancy. Subsequent development frequently failed to account for the needed realism expressed in terms of angular perspective. The culminating factor attributed to the failure in attaining the goal of three-dimensional representation was the inability of the existing two-dimensional media to portray a true three-dimensional message.

The development of holography has changed all that. This technique offers the capability of presenting a three-dimensional image on an essentially two-dimensional medium of expression, a piece of film or glass. Additional advantages such as the ease of measurement and chronologically oriented multiplexing can also be presented as definite advantages over conventional thematic cartographic techniques. Holography is the next step in the evolution of the cartographic field. Its characteristics demonstrated in this thesis prove that it is, indeed, a viable method for recording three-dimensional cartographic output on relatively conventional photographic film.

Continued Research Possibilities

Owing to the far-reaching implications of possible holographic applications, it is an understatement to say that additional investigation must be conducted in this area. Holography is presently being applied to problems in many disciplines. However, of most immediate concern to geographers is its application to mapping.

Computer constructed holograms are in the embryonic stages of development. From there, it is only one step to computer constructed holographic mapping capabilities. Involved study has already taken place in applying holographic techniques to topographic mapping.[41]

The applicability of this three-dimensional recording and display system, just to one aspect such as climatic data alone, offers wide latitude to anyone wishing to begin investigation in that area. The development of three-dimensional "isosurfaces" and related aspects of true three-dimensional cartography could provide for almost unlimited academic exploration. Indeed, holographic techniques applied to the field of cartography afford a true research frontier.

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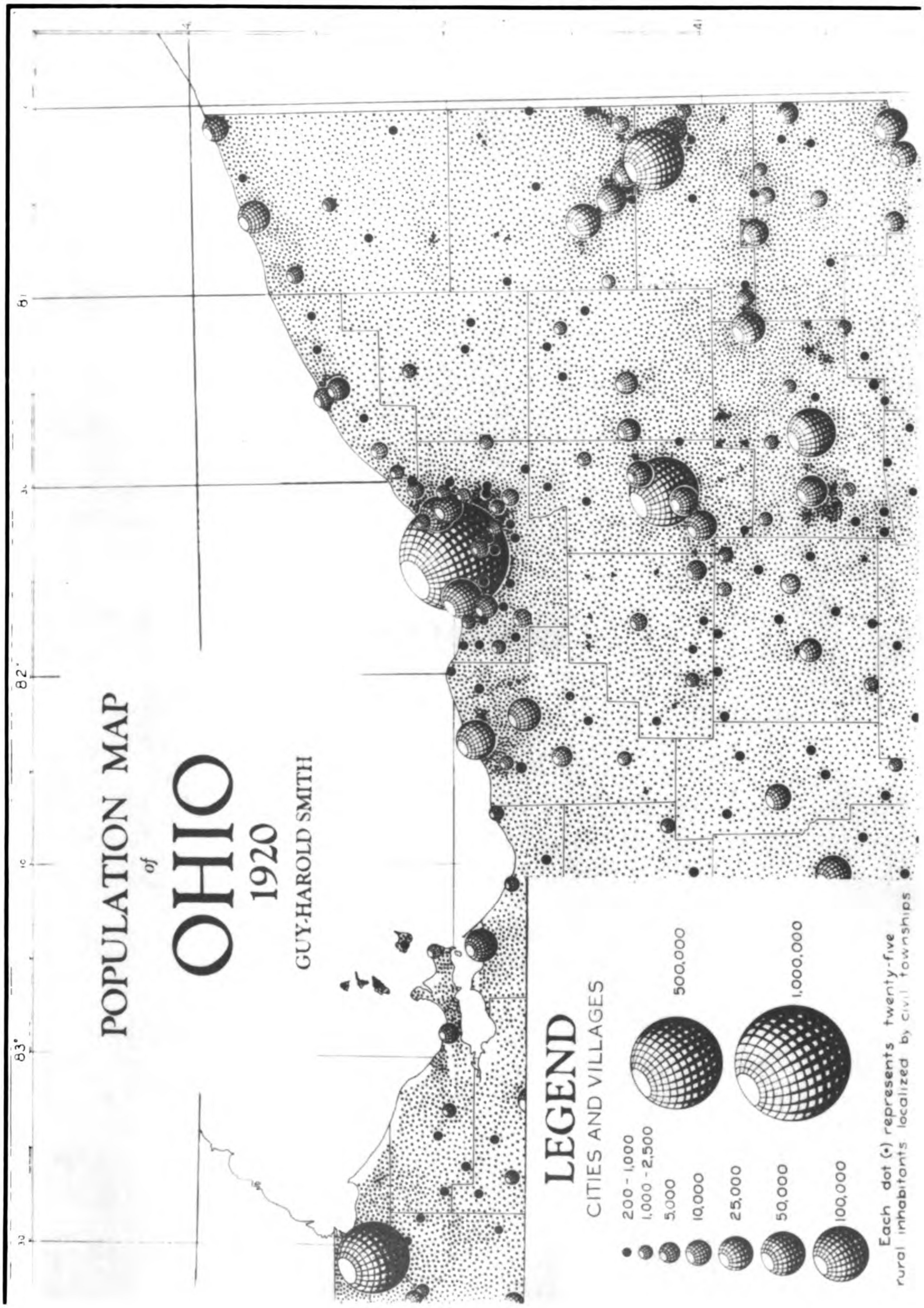
APPENDIX

Figure A1 - An Excerpt from Smith's 1920 Population Map of Ohio

Figure A1



POPULATION MAP
of
OHIO
1920
GUY·HAROLD SMITH
LEGEND
CITIES AND VILLAGES
200 - 1,000
1,000 - 2,500
5,000
10,000
25,000
50,000
100,000
500,000
1,000,000
Each dot (•) represents twenty-five rural inhabitants localized by civil townships
83°
82°
81°

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